The British Journal for the
Philosophy of Science

VOLUME V NOVEMBER, 1954 No. 19

PRIZE ESSAY ON *THE AGE OF THE UNIVERSE*

Judges' Report

IN the May 1953 issue of this *Journal* a Prize was offered for ' the best essay on *What is the logical and scientific status of the concept of the temporal origin and age of the Universe* (for example, as used in recent cosmological work). The essay should clarify the logical, theoretical, and observational aspects of the idea of assigning a quantitative age to the Universe.'

Twenty-six Essays were received : from Great Britain and Northern Ireland 11 ; U.S.A. 5 ; India 3 ; Canada 2 ; Italy 2 ; Austria 2 ; and Germany 1.

Though no essay of outstanding originality was received, the competition has been of value in producing several interesting contributions and in demonstrating the number of different ways in which the problem can be treated. About half the essays were genuine attempts to tackle the problem set, and these presented a variety of treatments. Some essays which were of interest could not be considered for the Prize because their main emphasis was on the observational or historical aspect, whereas the aim was to clarify the logical and scientific status of the concept. Of those essays which tackled the problem seriously, several had to be excluded either because of weaknesses in the treatment or because they neglected essential difficulties of the problem.

The Prize Money has been divided between Mr Michael Scriven of the University of Minnesota (£30) and Dr J. T. Davies of King's College, London (£20), with Honourable Mentions to Dr E. J. Öpik of Armagh Observatory, Northern Ireland, and Dr G. J. Whitrow of Imperial College, London. The Editorial Committee of the *Journal* has decided to publish, in addition to the Essays of these four competitors, two further Essays, those of Dr B. Abramenko of Mannheim and Dr R. Schlegel of Michigan State College.

We wish again to thank Mr Carl Bostrom of Milwaukee for his generous contribution towards the prize money.

H. JEFFREYS
July, 1954
F. A. PANETH
K. R. POPPER
L. L. WHYTE

NOTE.—The authors of the following Essays have made alterations for purposes of publication, but material changes have been segregated in footnotes. Further, it will be recalled that the closing date for the competition was December 1, 1953. Data relevant to the theme which have come to light since then have not been incorporated.—ED.

THE AGE OF THE UNIVERSE

Michael Scriven

It is not easy to decide whether the Ionians can properly be called scientists or whether they were simply philosophers. We incline to call them the first scientists because they were concerned to give a rational discussion of such problems as the nature of matter ; we hesitate because their answers, so far as our slender records show, were qualitative and not based on an experimental method. But it is clearly true that however much we wish to restrict the term ' science ', the greater part of its history and much of its current practice consists in research associated with that very problem : and it is also true that the foremost contributors to the field are still wrestling with difficulties that are at least partly philosophical, such as the prediction-requirements of a satisfactory physical theory, or the reality of the neutrino. One is at first inclined to say that the Ionians were asking a scientific question, but that they failed to give a really scientific answer. Perhaps a better description would be that they were asking a question which is partly scientific and partly philosophical, and that they had a very much simpler conception than we have of the sort of answer that can be given to each part, both in kind and in detail.

The other great problem that concerned the Greeks (as it had the Babylonians and the Egyptians before them) was the nature of the universe. Each of these problems had one particularly important sub-problem : in the first case, the origin of living matter ; in the second, the origin of the universe. The importance of these topics lies not only in their scientific interest but also in the fact that they represent in a sense the last stakes that the world-religions have in science. The origin of life is connected with the existence of the soul and the freedom of the will ; the origin of the universe is connected with the existence of a God. It is now doubtful whether any research concerning the nature of life will directly support or conflict with the official interpretation of any important creeds, though a century ago it did. But experimental production of living creatures would undoubtedly affect the *climate* of religious belief. Just as evolutionary evidence made it impossible to interpret the book of Genesis literally, i.e. to accept the separate creation of man, so biological creation would remove the last empirical task of the Creator since the moment of the Creation of the Universe. (I am not discussing the Catholic doctrine that a soul was given man at some specific moment in evolutionary history, not because I wish to say here that it is meaningless, but because it is certainly not susceptible to *empirical* test.)

Now, sophisticated theology no longer assumes a temporal origin to the Universe, and, since Augustine, would have been very rash to do so : the cosmological or first cause argument for the existence of God claims to demonstrate the necessity for a self-existent being in order that the universe may exist at all, whether from infinity or not. But it is certainly true that lay opinion in the religious as well as in the secular field regards the temporal origin of the Universe as natural and as necessitating a Creator. Even today a physicist such as Gamow can publish a book called *The Creation of the Universe* (2nd ed., Sept. 1952) in which he claims to discuss 'fundamental questions, such as whether or not our universe had a beginning in time' (p. vii) yet never realises that there may be some difficulty in the very concept of the *universe* (as opposed to a *process within it*) having a beginning. That is, he assumes that the question whether or not it had a beginning in time is entirely empirical, like whether or not π-mesons have their beginning in a μ-meson shower.

Let me make it quite clear that I do not regard the ordinary evidence, from recession velocities, condensation rates, etc., as being irrelevant to the question of temporal origin. It is relevant at least in the sense that it establishes, so far as it is sound, a lower bound to the age of the Universe. More precisely, however, its relevance is to the question of the length of the present phase of the evolution of the Universe. This is a related question, but a different one. Gamow discusses this question in detail ; but the question of temporal origin, i.e. the question of the duration of what he calls the 'pre-galactic past', he dismisses with the words 'Of course, we have no information about that era, which could have lasted from the minus infinity of time to about three billion years ago, . . .' (op. cit., p. 137). It follows that we have no evidence that it was not another galactic era, perhaps one of a cycle. And it is assumed that 'the minus infinity of time' is a self-explanatory term. So I think we may fairly conclude that the second great problem of the ancients, while it has produced the impressive body of scientific knowledge that is astronomy and cosmology, had also a philosophical content which has not yet been eliminated. Gamow and Whitrow today, as Thales and Anaximenes before them, are unaware of the relative proportions of these ingredients.

I now wish to develop the subject in the following way. I shall elaborate two objections to the procedures that are normally employed in ‘ estimating the age of the Universe ’. These lead to a consideration of the actual meaning of ‘ temporal origin of the universe ’, and a comparison of the time scale with the temperature scale and other physical scales. The only general conclusion that I hope to establish in this paper is that the identification of meaningful with verifiable statements, though a useful prophylactic for preventing philosophical giddiness, is not entirely satisfactory. The problem of the temporal origin of the universe is a problem of meaning before it can be a problem that science can decide.

There are several ways of estimating the ‘ age of the universe ’. We obtain lower bounds from various estimates of the age of the earth and of meteors (about which, of course, no *philosophical* problem arises since we can give a clear meaning to the phrase ‘ the origin of the earth ’) from the fluorine content or radiogenic lead isotope ratios in rocks, salt deposit rates, etc. These are again lower bounds for the age of the earth or the meteors, and lead to an estimate of the order of 3×10^9 years. Astronomical evidence similarly arises from extrapolation of various processes whose present rate we can measure : these include the rate of dispersion of star clusters, of colligation of interstellar dust, of aging of stars, of recession of the nebulae, of energy distribution in our galaxy, etc. There is a good deal of interest in a specific discussion of the techniques employed and the possibility of improving them : but, as I am challenging on logical grounds the adequacy of *any* of this evidence for purposes of estimating the age of the universe, I shall not go into details here. But two things must be noted. First, these estimates are all fairly rough and no-one has claimed otherwise. Second, within the limits of error there is an overall agreement on a value of the *order* of 5×10^9 years. The original dispute about the ‘ short ’ and ‘ long ’ time-scale has now been resolved ;[1] and recent work by Bowen, Baade, and Hubble, together with some results of Thackeray and Wesselink, on the classical cepheid variables has led to a revised estimate from recession rates that generally speaking improves the overall correlations.[2]

The first criticism to be made is this : the suggestion of all these results is that the universe was *very* different in constitution and appearance a few thousand million years ago—yet in order to obtain an initial moment one must assume the propriety of extrapolation until the measured variable is zero. The galaxies are receding : it is very plausible to assume that we can extrapolate their rate of expansion backwards for a considerable time. But is it at all plausible to assume that under the extraordinary conditions of extreme compression, when for example the nuclear forces were greater than the gravitational forces, the expansion rate was even remotely related to the later rate, or indeed that there was expansion at all ? The general hypothesis which the evidence suggests, itself renders unlikely the calculation of the original moment of the process. Even if there was an initial moment for the universe, we have only the slenderest evidence for when it was, because our assumptions rest on a state of the universe very different from its state at moments near to the initial moment. Our extrapolations may give us some agreement about the moment when expansion began according to the present growth-law, but are inadequate for deciding when the universe began expanding (let alone the question when it began). The same argument applies to all the astronomical rate-measurements, and it has been generally overlooked. It is quite different from the argument that the data we have are such as to allow only an approximate estimate anyhow. There is nothing implausible about the suggestion that expansion may have begun 10^{90} years before it adopted its present trend : nor is it plausible—we simply have no evidence on the matter.

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[1] See e.g. *Rev. Mod. Phys.* **22,** 124–126

[2] *J. Brit. astr. Ass.*, 1953, **63**, 133

The second criticism is the more fundamental and derives from an elaboration of the first. Not only are our estimates of the temporal origin of *the various processes* highly unlikely, they are also in an important sense wholly insufficient grounds for believing in a temporal origin for *the universe itself*. There is no reason to doubt, and a number of reasons to believe, that there were phases in the evolution of the universe prior to the present ' expansion ' (I am using this term as a name for the present phase without committing myself to the view, opposed by Corben, E. Findlay-Freundlich, and some kinematical relativity theorists, that the expansion is real). In that case, the estimates, though interesting, lose most of their sensation-value. The correspondence between the estimates suggests that most of the process-rates we employ adopted their present trend at about the same time, which is likely enough since the underlying laws are independently identifiable as applicable to dynamical systems of (approximately) the same kind.

A particular case which has some special interest is where a prior state of the universe approximated stability: we might have a homogeneous distribution of relatively inert atoms, or, interpreting stability in a different sense, a uniform radiation field. The interest in such a case lies not in the fact that we have any evidence that it existed but in the fact that it is doubtful whether we could ever have such evidence, although there seems nothing *logically* impossible in the description. The doubt arises from the fact that if no asymmetrical process is continuing, there can be no traces of it, hence no estimate of the duration of such a period. It would be simple to conclude that any such supposition is in fact meaningless since either the second law of thermodynamics or the laws governing agglomeration (electro-magnetic or gravitational) would make it impossible. But the universe is not now generally accepted as a closed system within the meaning of the second law, and both laws give only a *probability* against the 'stable' state: if we cannot claim the passage of time, there can be no probability that the condition is transient. Thus, it is improbable that a static state could subsist for long if it is granted that it does: but if it does, there can be no way of saying how long it subsists, i.e. no distinction between an instant and an eternity. Suppose that everything within the universe suddenly ceases all movement for a minute. The supposition is untestable and in fact unknowable since if all movement ceases we shall not be aware of it, nor will clocks show it. It appears we must assume, either that the supposition is meaningless, or that we have a time sense independent of brain states. Now it is intuitively very unsatisfactory to say that it makes sense to say (*a*) that everything in the universe except one clock stops moving for one minute, or to say (*b*) that for one minute nothing in the universe stops moving except the clock, but *no* sense to say (*c*) that both (*a*) and (*b*) are true, i.e. that everything stops moving for one minute. Yet, if one says this has meaning, how does one hope to decide whether it is true? And if one cannot do this, is science to admit that it cannot (even in principle) always decide what is the case?

We are now asking ourselves the very fundamental question: what is the difference between saying that the Universe has an origin in time and saying that each of the processes of change within the Universe has an origin in time? We are already beyond the question to which our present data give us an answer, viz. When was the temporal origin of the *present* processes of change? and I hope it is apparent that the further questions are the really fundamental ones.

The 'age of the Universe' can, of course, be *interpreted* to mean 'the age of the present form of the Universe', but it is clearly more than a little unsatisfactory, supposing that a cyclic expansion and contraction is taking place, to say that each cycle marks a new Universe. We take the Universe to mean everything that exists : thus the 'origin of the Universe' is the 'origin of the first thing', no matter whether part of the present phase or not.

Stuart Hampshire, in a series of Third Programme talks on Spinoza, suggested that the root of the trouble lies in the word 'thing'. How can we ever decide how many things there are in a room ? Clearly such a question presupposes an agreement about the level of interest—do atoms count, do electrons, do shadows, thoughts, etc. ? For the origin of the Universe there seems to be a corresponding problem. Suppose we reach a prior agreement that, say, photons or electrons count as things and that we then discover the first moment when one of these existed. Would this be the temporal origin of the Universe ? Only if that idea of the structure of matter is sound ; for if we later discover certain short-lived particles whose decay produces electrons, we would then have to search for *their* trace in the pre-electron time-record. Already it is clear that the practical possibility of an answer is becoming exceedingly remote. But this in itself is indicative of a weakness in the previous theoretical approach : it is wildly misleading to suggest that anything remotely connected with a temporal age to the Universe has yet been discovered. We have seen two sources of trouble apart from the two original criticisms : first, the measurement of the duration of a stable state ; second, the dependence of the investigation on other research or upon an arbitrary decision about what it is that is capable of existence.

The practical effect of this second consideration is serious. It suggests that the existence of a temporal origin to the Universe is of the same nature as the existence of a fundamental substance, because only in so far as we can give a sense to the statement 'Science has now identified the fundamental substance' can we give a sense to the statement 'There was a definite moment when this substance originated'; i.e. 'The Universe had an origin in time'. And the assertion that there is a fundamental substance, and that we have found it, is a dogma that could never be proved—for there is no way of proving that future discoveries of yet-more-fundamental substances are impossible. Therefore there can be no may of proving, *even if we had the evidence of an invisible, fully-equipped observer present in the past,* that the Universe began at a certain time. This point is quite independent of the previous points I have made, which view the evidence as we see it from the present. It may appear to be dependent on the assumption of an evolutionary Universe, developing from a first state of maximum simplicity. But I have considered that form of development only for the sake of simplicity. Suppose we have the records of intangible instruments (ignoring the implications of that assumption for the moment), which show nothing and then the sudden appearance of a supernova from which, let us assume, we can trace the later development of the present Universe. Is this the moment of creation ? Only if we assume that the instruments employed are adequate for recording everything that can be said to exist. Furthermore, the detection of existents is not only a matter of getting down to successive micro-levels : it is also a question of detecting non-material existents such as fields. Can there be fields without material existents ? It is certainly conceivable that the meters should record a field-strength while the cloud-chambers, etc., record no particles. And, as in the case of the brain-state which remains unchanged while a ' time-sense ' registers, we cannot make a logical conclusion dependent on what appear to be empirical possibilities. If a field appears to be present, it will certainly make the assertion—that the Universe has not yet begun—entirely unsatisfactory.

It must be made clear, however, that the above argument does not in itself show the concept of a temporal origin to be meaningless, it establishes only what I should term the essential impossibility of assigning a specific date to it. The first arguments in this paper were aimed at practical difficulties, and the above argument is aimed at a limit difficulty ; we must turn elsewhere if we are to find a conceptual inconsistency.

The question we must now ask arises from consideration of the assumption of the hypothetical observer. What is meant by the statement ' Nothing exists at time T_1 '? Without a clear answer it is very difficult to understand ' Time T_2 is the first moment when something existed '. (I am not at the moment denying that it *may* be possible in terms of something like Milne's τ-scale.) We are strongly inclined to say that it makes sense to say that ' Nothing exists ' on the grounds that it makes sense to say of any particular thing that it does not exist and we can perform a thought-experiment in which the number of things in the Universe decreases until there is only one and then it, too, vanishes, leaving nothing at all. Now, the rule for selection can take any form, so that if one is to say ' The last thing can't vanish ' one appears to be committed to saying ' None of the things can vanish ' since any one can be last. But there is a genuine conflict here between criteria of meaning. It is logically impossible to verify the statement ' The last thing has vanished ', yet there seems to be some conceivable experience of a hypothetical observer that would be correctly reported in the above terms. One might put the conflict by saying that it is *logically* impossible that *this* hypothetical observer could be an actual observer : can one say that an observer whose existence is impossible, is a possible observer ? Suppose that we agree to say, tentatively, that a statement is *verifiable* only when we can describe what an observer would actually observe if he were instrumentally present and it were true ; while it is *meaningful* as long as we can describe this while *not* requiring that it be logically possible that he be there. Now our discussion of the ' last thing vanishing ' is exactly parallel to that of ' the first thing appearing '. There is some interest in comparing it with the familiar arguments about the meaning of position, velocity, and inertia when there is only *one* particle left in the Universe. The conclusion these arguments reach is sometimes put as : ' A single particle can have (e.g.) no velocity '. This suffers from a similar ambiguity to the statement ' The last particle cannot vanish '. What it means is that the concept of velocity requires a frame of reference, normally provided by other existents, and thus *cannot apply* in their absence. People sometimes resist this conclusion because they feel that the presence or absence of other bodies cannot affect the simple fact that a particular body has velocity. (This argument seems even more plausible when applied to inertia, and rather less so when applied to position ; an observation perhaps correlated with the fact that these quantities involve three, and one, independent variables compared with velocity's two, and hence appear to have more and less ' measurable reality '.) If one wants to say that a body can have position in the absence of other bodies, it must be explained in terms of a hypothetical observer : and the concept of position can then at best be described as meaningful but not verifiable—as we have (somewhat generously) taken these terms.[1]

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[1] The best discussion of the arguments about the independent existence of space, apart from Einstein's (' There can be no space . . . without gravitational potentials ; for these confer upon space its metrical qualities without which it cannot be imagined at all ') is in E. G. Barter's very recent book, *Relativity and Reality*, New York, Oct. 1953, especially Chapter XV.

It is not possible to push this argument to an absolute conclusion, though consideration of a number of these cases makes us less and less willing to say that there is any meaning in 'Nothing exists'. This is not to be taken to mean that 'Something exists' is *necessary*, i.e. that the Universe *necessarily exists.* The idea of necessary existence (and I cannot justify this point fully here) is equivalent to the idea of deductive proof of future occurrences, and is in an important sense inconsistent with our logic.

We can only suggest that a positive account must begin with such cases, go on to consider the meaningfulness of such concepts as colour when there are no things, motion when there is no movement, temperature when there is no motion, time without change. Each case requires a different set of examples. The only one that concerns us here is time without things, for unless one can give this a meaning, one can give none to the time of the first things. Now Milne's τ-scale suggests that one transform the time-scale, setting the minus infinity point to correspond with the first moment. This has an interesting parallel in the case of temperature as one can take a logarithmic scale of temperature (K') in which the Nernst Heat Theorem or Third Law of Thermodynamics is given a mathematical interpretation by making absolute 'zero' correspond to minus infinity degrees K'. This is essentially *unlike* the time case in that there is no possibility that there are long ranges of temperature below -273° C corresponding to the possible long ranges of time before 5×10^9 years ago. We may be wrong in thinking absolute zero is unattainable (we must of course abandon the kinetic energy definition at low temperatures in favour of the thermodynamic definition);[1] we cannot be wrong in the belief that the quantities we measure, e.g. paramagnetic effect, entropy, energy, cannot decrease below zero and that we have almost attained this value. One can give a *sense* to the phrase 'negative temperature (Kelvin scale)'—and it has been done—just as one can give a *sense* to the idea of a circle with a negative radius (e.g. in terms of orthogonal projection of actual circles), but this does not mean that *in the present sense* it is meaningful to talk of negative temperatures or circles of negative radius. But any law of unattainability in the time case must rest on an empirical determination of the first moment in terms of our present time scale, *which does not have a zero-point.* The unit of temperature measures a change in some quantity relative to its zero value: that of time does not. No transformations can conceal the fact, a logical fact, that time as we take it, but not temperature as we take it, allows meaningful reference to any past date. This does not mean that all past dates correspond to physical states. So-called steady-state models of the Universe, based on the perfect cosmological principle, take it that they do. Now if this is meaningful, as it appears to be, it is certainly not verifiable. For clearly we shall never find evidence from an empty state with a date attached, since all our dates are determined from existents : hypothetical observers cannot bring back evidence, so it is a tautology to say that however far into the past we delve, we shall always find evidence of an existent state. But the claim of infinite age is at least a claim that beyond any apparent beginning there are still further aeons of existence : and the claim of the ' new cosmologists ' is of course much more specific, viz. that the overall ' appearance ' of the Universe was always the same.

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[1] See F. Simon et al., *Low Temperature Physics*, London, 1952

My conclusion would be this : no verifiable claim can be made either that the Universe has a finite age or that it has not. We may still believe that there is a difference between these claims : but the difference is one that is not within the power of science to determine, nor will it ever be.

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THE AGE OF THE UNIVERSE

J. T. Davies

Theme

The observations which are compatible with temporal origins of the earth, the solar system and the universe are briefly mentioned, prior to examining the assumptions implicit in the hypothesis of temporal origin which the observations were designed to test. No decisive observation enables us to distinguish between theories of a temporal origin of the universe and the theories of infinite time (continuous creation) ; the aspects of the galaxies offer no test of either theory without invoking additional assumptions.

Curvature of time is rejected as being a complication at present scientifically unnecessary, as is also the hypothesis of continuous creation.

The view maintained is that the temporal theory based on linear extrapolation is acceptable until it be disproved. Various new techniques which may be useful in attempting to refute this theory are discussed.

General Introduction

The conception of a birth of man's material environment dates from furthest antiquity, and the analogy has been extended to relate to the process of city-states, empires, and civilisations, the familiar concepts of birth, adolescence, maturity, and decay. Famous or notorious in this connection are such men as Plato, Vico,[1] Spengler,[2] and Toynbee. Uncertainties are unfortunately rife in drawing such parallels : in particular the data may have been unconsciously selected to illustrate the theory. May not the analogy itself be an over-simplification ?

Difficult though these objections may sometimes be to refute, the *scientific* theories of the universe and its development possess a saving grace in that the structure of speculation, although no more solid than before, can conceivably be brought crashing down by new experimental observations. This, indeed, forms one of the main thoughts of this paper—the ' intersubjective ' checking of cosmogonies with new observations must needs occupy an increasingly important position in theories of the origin of the universe.

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[1] G. Vico, *La Scienza Nuova*, 1725

[2] O. Spengler, *The Decline of the West*, English translation, 1934

Observational

(*a*) AGE OF THE EARTH. This age sets a lower limit on any estimated age of our galaxy or of the universe. From radio-active decay and from such other geophysical measurements [1] as the salinity of the oceans, the time elapsed since the formation of a solid terrestrial crust is calculated to be between 2.0 and 3.35 × 10^9 years.

(*b*) AGES OF THE MOON, METEORITES AND OF MERCURY. In 1942 Paneth et al [2] deduced from the He contents of meteorites that their ages ranged up to 7 × 10^9 years, but more recent studies [3] suggest that these figures may be upper limits : Gerling and Pavlova,[4] from the A/K ratio of meteorites, have recently found ages of 3.00 — 3.03 × 10^9 years. From the times for the Moon and Mercury to have taken up their present orbits Jeffreys [5] quotes an age of about 10^9 years.

(*c*) AGE OF OUR GALAXY. (*i*) *Stellar Motion.* The observed distribution of stellar velocities is not in accord with an equi-partition of energy. If the latter be the end-state in an aging galaxy, the present velocity distribution suggests the system has existed in approximately the present form for 3 — 5 × 10^9 years.[6]

(*ii*) *Stellar Energy Sources.* There is evidence that stars derive their energy by the ultimate conversion of H into He. Further, it can be shown that the stellar life-span is inversely proportional to the square of the mass, and, if we consider stars on the verge of hydrogen exhaustion (' unquiet ' behaviour) we observe that they are about five times the mass of the sun. The mass-life relationship then gives an age for these stars of 2 — 3 × 10^9 years.

(*iii*) *Dynamics of Star Clusters.* Loose star clusters, if assumed to have been disintegrated by tidal forces give an age of about 10^9 years.[7]

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[1] H. Jeffreys, *The Earth*, Cambridge, 1924, 1952 ; G. Hevesy and F. A. Paneth, *Radioactivity*, Oxford, 1938 ; F. A. Paneth, ' The microanalysis of the inert gases ', *Endeavour*, 1953, **12**, 5 ; S. C. Curran, ' The Determination of Geological Age by means of Radioactivity ', *Quart. Rev.*, 1953, **7**, 1

[2] F. A. Paneth et al., ' Meteorites and the age of the solar system ', *Nature*, 1942, **149**, 235

[3] Paneth, *Endeavour*, loc. cit. ; F. A. Paneth et al., ' Production by Cosmic Rays of Helium-3 in Meteorites ', *Nature*, 1953, **172**, 200

[4] E. K. Gerling and T. G. Pavlova, ' The Determination of the Geological Ages of Stony Meteorites by the Argon Method ', *Dok. Akad. Nauk. S.S.S.R.*, 1951, **77**, 85

[5] Jeffreys, op. cit.

[6] B. J. Bok, quoted in ' The Age of the Universe ', *Rev.Mod. Phys.*, 1949, **21**, 374

[7] D. ter Haar, ' Cosmogonical Problems and Stellar Energy ', *Rev. Mod. Phys.*, 1950, **22**, 119

(*d*) THE AGE OF THE UNIVERSE. Exhaustive studies of the spectral lines of the distant nebulae, particularly by Hubble, have shown that the red-shift varies approximately linearly with the distance of the nebula from us. This shift he interpreted as a Doppler effect, the rate of recession of any nebula being greater by 106 miles sec.^{-1} for each million light-years travelled by the nebula.

Hubble divided the mean distance between neighbouring galaxies by the measured velocity of recession, obtaining a time which would have elapsed since the material forming the universe was in an initial highly compressed state. This was 1.8×10^9 years ago. Recently, however, the data for intergalactic distances have been subject to considerable revision: Behr[1] in 1951 gave a figure nearly twice the former value, increasing the time interval to about 3.6×10^9 years. At Mount Palomar, Baade[2] has confirmed (1953) the new intergalactic distances; the age of the universe is given as 4×10^9 years. The latter figures, we may note, are compatible with the geophysical and other measurements, whereas Hubble's earlier value[3] is not.

Assumptions in Interpreting the Observations

(*i*) The laws of physics are independent of the distribution of matter and of time. This postulate of simplicity underlies, of course, all scientific investigation. But since the interpolations and extrapolations we make in the laboratory involve very small times and (by astronomical standards) practically constant distributions of matter, the fact that certain simple, successful hypotheses have been repeatedly confirmed in the laboratory does not mean that there is any logical ground for considering that the same simple laws will hold with vastly greater variations in the matter distribution and in the time intervals. The light from the most distant nebulae was emitted some 500 million years ago, and, as Milne suggested, the atoms then may possibly have had slightly lower characteristic frequencies. Likewise the methods *c*(i) and *c*(iii) are based on an assumed constancy of gravitational interactions over enormous time intervals. The latter point has been queried by Dirac and by Jordan, both of whom prefer a time-variable gravitational constant.

[1] A. Behr, 'On the distance scale for extra-galactic nebulae', *Astr. Nachr.*, 1951, **279**, 97

[2] W. Baade, referred to in 'Current Scientific Projects of the National Geographic Society', *Nat. geogr. Mag.*, 1953, **104**, (1), 143

[3] E. P. Hubble, *Science in Progress*, Yale, 1942

(ii) It is assumed that the astronomical observations are precise in their simple form. Radio-active decay, the proportionality between the red-shift and distance, and the mass-lifetime relationship for the stars may not be exactly expressed by such simple terms. They may be but first approximations. Consider, for example, that F, the mean intergalactic distance, is continuous, and varies about $F(t)$ thus :

$$F(t-\Delta t)=F(t)-\Delta tF'(t)+\frac{(\Delta t)^2}{2!}F''(t)\quad -\quad \ldots \text{(i)}$$

where primes denote derivatives and t is time. If the time interval Δt, in which we are interested is short, this Taylor series reduces approximately to :

$$F(t-\Delta t)=F(t)-\Delta tF'(t)\quad .\quad .\quad .\ \text{(ii)}$$

the square (and higher powers) of the small term Δt being neglected.

In finding the 'age' of the universe, we wish to find Δt_0 such that $F(t-\Delta t_0)=0$. In using (ii) in the form

$$F(t)-\Delta t_0F'(t)=0\quad .\quad .\quad .\quad .\ \text{(iii)}$$

and solving for Δt_0 (using the red-shift value for $F'(t)$ and the intergalactic distances for $F(t)$) we apply (ii) to the region where Δt is not small (see Fig. 1). We must, therefore, test experimentally the further consequences of our hypothesis that such a simple extrapolation is satisfactory in correlating our different observations, i.e. that $F''(t)$, $F'''(t)$, etc., are negligible.

In the same way $F(t)$ can represent, e.g. the extent of radio-active disintegration ; the epistemological conclusions are identical.

Fig. 1 illustrates these points. We measure, at the present time, $F(t)$ and $F'(t)$, from which we extrapolate linearly back to zero F and hence find the time interval representing the age of the universe.

The data used in calculating the age of the universe are not sufficiently precise for terms such as $\frac{(\Delta t)^2}{2!}F''(t)$ to be taken into account : without these or other information it is impossible to say whether an expansion might not be merely a phase of a more complex phenomenon such as pulsation.

(iii) New forces may be operating. Although we prefer not to invoke new forces unless the old concepts have proved inadequate, there is no logical basis for assuming that only terrestrial or galactic forces are operative over the entire universe. The matter can only be decided empirically. For example, Einstein's cosmological constant, introduced into his cosmogony to overcome gravity in a static universe, is no longer necessary now that the universe is held to be expanding. It can, however, be used to lengthen the time-scale in that it would imply that expansion was an accelerated process ($F''(t)$ is not negligible),

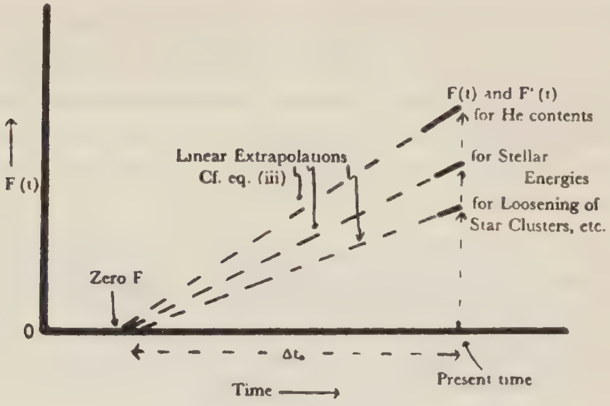

FIG. 1.

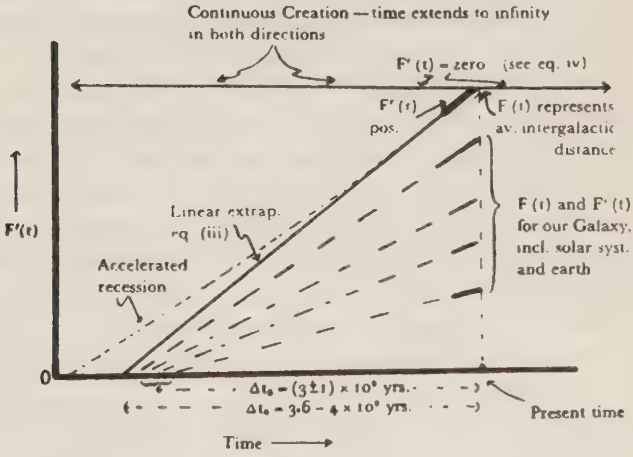

FIG. 2.

thus moving the beginning of the universe further back in time, as in Fig. 2. In this way Alpher showed that the age of the universe could be nearly doubled.

Other new effects which have been suggested are an interaction between gravitational potential and spectral frequency (allegedly responsible for the red-shifts), and non-linearity of time-scales (see below).

Since the recent doubling of the age calculated from the linear extrapolation, the interest in new forces seems to have declined somewhat.

Continuous Creation

Bondi and Gold, in their theory of continuous creation (reviewed by Spencer Jones),[1] besides invoking assumption (i), assume :

(*a*) that, though there are local differences, there is a large-scale homogeneity in the universe. This is supported by surveys of the spatial distribution of the galaxies,

and

(*b*) that the large-scale appearance of the universe does not change with time. The universe is thus taken to be infinite in extent, and time to extend infinitely in both directions. Creation of matter is a continuous process going on through all time, exactly off-setting the reduction in density due to expansion.

On this basis (the 'perfect cosmological principle') one may compute that, to balance exactly the dilution of matter due to expansion, matter must be created at the rate of 10^{-43} gm. sec.$^{-1}$ cm.$^{-3}$. This is far too small to be detected by direct observations. The created matter is postulated to be continually condensing into new galaxies, which eventually recede and are replaced by new ones. This idea is said to be supported by the older observation (Jeans and Hubble) that some galaxies are more 'nebulous' (Plate 1) than others (Plate 2) which have 'evolved' further by condensation into individual stars : later we shall discuss the validity of this interpretation. Bondi and Gold accept the value of a few thousand million years for the age of our own galaxy, which they consider a relatively young one. Thus the theory of continuous creation provides us with a picture rather like that of a living population : individuals are born, age and die, but the population may remain in a steady state.

Evidence of Aging

That the earth is aging (many terrestrial phenomena like the explosion of uranium atoms being irreversible) is not seriously disputed. The same may be said of the solar system and indeed of our galaxy as a whole ; the present controversies arise solely in the interpretation of the observational data from galaxies outside our own. Lemaître and Gamow uphold aging here, while the adherents of continuous creation maintain that there is large-scale homogeneity with respect to time. The latter implies that increases of entropy are impossible as the latter is always being carried beyond the observational horizon through the recession of the galaxies. If, however, aging occurs outside our own galaxy, one can maintain the *universal* character of the Second Law of Thermodynamics : there is no evidence concerning the conclusion from molecular probability theory that localised reversals should occasionally occur.

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[1] H. Spencer Jones, 'Continuous Creation', *Proc. roy. Inst.* G.B., 1953, **35**, 336

Nebulae of the type in Plate 1 are often called ' young ', while others (Plate 2) in which the diffuse matter has clustered predominantly into stars are called more ' evolved '. Those who use this as evidence against the theory of a simultaneous temporal origin of the whole universe must needs assume tacitly that all the galaxies ' evolve ' at about the same rate. It is as if an observer, allowed only a glimpse of an orchard, was required to decide whether or not all the trees were the same age. Some of the trees might be tall and bearing fruit ; others smaller and less mature. But without further information (e.g. on localised soil and shade effects and species variations) such an observer has no way of deciding whether the trees were planted contemporaneously or not, i.e. whether the smaller and less mature trees are merely stunted and retarded or whether they were planted later. So with the galaxies : without detailed knowledge of the localised radiation pressures, gravitational fields etc. during the history of each galaxy we cannot admit the different appearances as being evidence against any theory.

Time Scales

' Time ' has been used in many different ways :[1] De Sitter's mathematical scheme of representing an empty universe, for example, has curvature in the time dimension as well as in the spatial dimensions. This means that the coefficients in the tensor equation of his theory are variable, implying that at very great *distances* time measure may be retarded ; the red-shifts of the nebulae are thus explained without postulating any recession. Milne suggested that the time-scale varies with the *age* of the universe, the frequencies of the spectral lines being less when the nebulae were emitting, at times of the order 100 million years ago.

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[1] M. Johnson, ' Time and Space in Philosophies of Science ', *Amer. Scient.*, 1951 **39**, 412

From this brief summary we see that the age of the universe is a concept whose validity depends on the applicability of the time-scale of laboratory physics to the universe. If this postulate of independence (the simplest we can devise) is *not* allowed, no linear extrapolation is acceptable.

Logical and Philosophical Problems

What existed before the creation of the universe? How was the universe created? When was the universe created?

The last question can be given an answer directly from the red-shifts; the second has been a subject of scientific speculation (Lemaître, Gamow [1]), but the first is the hard core of the whole subject. Our minds recoil at the idea of times before the beginning, and still we cannot improve on St Augustine's answer.

If the universe or space is expanding, if the red-shift is taken as a simple Doppler effect, we must postulate this zero in time, with a concomitant zero (or near zero) in space. Even if, with Milne, we consider that the red-shift may be due to a change in the physical laws with time, we must still postulate a zero if the red-shift is extrapolated.

If, however, we find the idea of the zero of time too uncongenial, we may explain the red-shift otherwise, either as due to curvature of time (de Sitter) or as implying recession without expansion of the universe (continuous creation). Here we are finding a way out of the philosophical problem by putting new parameters in the scientific theories, thereby making them less simple.

How can we choose between the rival theories of the universe? However our hypotheses may be coloured by aesthetic judgments, philosophical attitudes or preconceived ideas (birth and aging of an individual; continual loss and replenishment as in a living population) the ultimate test lies in comparison of the deductions with new and preferably independent observations. Only theories never disproved are acceptable: only theories tested in many directions can be called satisfactory. For the latter purpose let us begin with the simple theory of linear extrapolation, irrespective of the philosophical difficulties it entails.

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[1] G. Gamow, 'The Origin and Evolution of the Universe', *Amer. Scient.*, 1951, **39**, 393; *The Creation of the Universe*, New York, 1952

The *method* of testing the theory is as follows. From an extrapolation (Fig. 1) with $F(t)$ (say) a logarithmic function of the amount of helium in certain rocks, one obtains the parameter Δt_0 (called an age). We now use Δt_0 and experimental rate data ($F'(t)$) for (say) the *Rb–Sr* conversion, the annual addition of salt to the oceans, etc., to calculate present values $F(t)$ for the amounts of *Rb* and *Sr*, the salinity of the oceans, etc. These calculated figures can be checked by observation. All such attempts to *disprove* the extrapolation have been unsuccessful, and we have therefore retained the hypotheses of similar temporal origins and of the linearity of the appropriate relationships. Checking the coincidence of the Δt_0 values (Fig. 2) is an equivalent procedure.

At present the controversial subject is the inclusion of the red-shift data of the galaxies on this type of plot ; $F(t)$ is now the mean intergalactic distance and $F'(t)$ the mean rate of increase of such distance. The only conclusive test is that Δt_0 found in this way must not be less than the 3×10^9 years quoted above. Although this condition is satisfied with the new intergalactic distances ($\Delta t_0 = 3.6 - 4 \times 10^9$ years), there has been no critical observation devised to distinguish whether the recession (if such it be) *does* imply increasing intergalactic distances ($F'(t)$ positive) or whether new creation suffices to compensate for the recession. The equation :

$$F'(t) = \text{rate of recession} - \text{rate of creation} \quad . \quad . \quad \text{(iv)}$$

shows that in the latter case $F'(t) = 0$, i.e. the mean intergalactic distance is constant and $\Delta t_0 = \infty$, (Fig. 2).

All hypotheses, however strikingly they are confirmed, can have no logical validity. Analogy and extrapolation are likewise fallible. Further, unless we can conceive of a critical observation which could distinguish between rival theories, the latter are either 'unscientific' or are stating the same thing in different guises. As Popper has emphasised,[1] the criterion of a scientific theory is that it must be possible for an observational check to be devised (however impractical with existing techniques), by which it might be disproved.

Concerning the various cosmogonies, our verdict must be that they stand 'not disproved'. In this situation, let us continue to select initially for our attention[2] the simpler theories, i.e. those having fewest arbitrary

[1] K. R. Popper, *Logik der Forschung*, Vienna, 1935 : 'The Nature of Philosophical Problems and their Roots in Science', this *Journal*, 1952, **3**, 124

[2] H. Jeffreys, *Scientific Inference*, Cambridge, 1931

constants and small, integral coefficients. Such theories, although the concept of simplicity may not always be easy to define,[1] are both congenial to us and of demonstrated value in the laboratory. They also offer keener tests[2] with the meagre observational data at our disposal: from these points of view the age of about 4×10^9 years is acceptable.

Does the universe pulsate? This question can only be answered scientifically if there is evidence available of either pre- or post-expansion phenomena. If there were a complete breakdown of matter to ageless elementary particles before a general expansion began, previous conditions must remain unknown: there is no evidence that any atomic species has an age greater than 4×10^9 years. Larger telescopes might, however, conceivably show a limit to the expansive process or even a contraction at distances hitherto beyond observation.

Relativity Theory

In preferring the theory of an expansion from an initially highly condensed universe to that of continuous creation, we remain on familiar ground, as either the general theory of relativity or a modified classical theory can predict the former phenomenon. Thus, we may consider that space itself is expanding as a function of time: the recession as interpreted by the Doppler effect is not limited by the velocity of light. In the latter the galaxies are thought of as dispersing like the particles in a cloud of smoke, their velocity being limited by that of light. A telescope larger than 400 in. should be able to decide between these theories. In either case, however, the extrapolated age is of the same order of magnitude, and it seems preferable to use the linear extrapolation rather than invoke the cosmological constant. The latter does not enter the theory of relativity in the nearer regions of space in which it has been so elegantly tested, nor is it necessary in the expanding (non-equilibrium) Einstein universe.

The Value of Theories of the Cosmos

A scientific theory is alive only while it stimulates further research which may disprove it. New developments, depending on observations in quite different fields, have shown how stimulating are theories of the origin of the universe.

By means, for example, of V-2 rockets and balloons the primary

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[1] Popper, *Logik der Forschung*, 87-8

[2] Ibid., 92

cosmic radiation has been shown[1] to be a thin rain of fast nuclei. Although at present none of the widely divergent hypotheses concerning the origin of the nuclei is generally accepted, preliminary attempts to test the cosmological theories by these findings have already been made.[2]

Galactic rotation and spiralling. The slow rotation and number of turns of the spirals of the galaxies have proved of considerable interest. The figures of Plates 1 and 2 show that there are not more than about one and a half turns of the spiral, an observation generally true. C. von Weizsäcker,[3] analysing mathematically the features of the turbulent motion leading to the formation of such 'arms', found an age of the order 10^9 years. Eddington reached the same conclusion studying the Milky Way.

Radio Astronomy. Ratcliffe[4] suggests that some short-wave radiation originates in interstellar matter, properties of which may prove important in testing the cosmogonies.

The He^3 *and* He^4 *contents of the meteorites*[5] are of interest both in relation to the possible origins of the meteorites and to the evaluation of cosmic ray intensities outside the magnetic field of the earth and possibly at times long ago.[6]

Atomic physics is an essential basis of the theories both of Gamow and of Hoyle. But the alarming multiplicity of 'fundamental' particles may necessitate[7] a new, unified mathematical physics: that fundamental particles with very high energies interact by forces not independent of the relative velocities has recently been suggested by Cockcroft.[8] If this is confirmed, assumption (i) may be seriously in error in cosmogony.

In the last three years Stebbins and Whitford[9] have claimed *evolutionary changes in galactic spectral luminosities.* In the young galaxies (from which the light has taken longer to reach us) the proportion of red to blue stars is greater than in the nearer and older galaxies. If this proves to be general, and if intergalactic dust—recently found by high-altitude rockets to be denser than supposed—is unimportant in this effect, a direct refutation of the 'Perfect Cosmological Principle' is at hand. Another possible method of disproof would arise from an observed spatial curvature, manifested in any variations in the galactic distributions which might be observed with *larger telescopes.*

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[1] C. F. Powell, 'The Cosmic Radiation', *Proc. roy. Inst. G.B.*, 1952, **35**, 39

[2] cf. ter Haar, op. cit.; F. Hoyle, *The Nature of the Universe*, New York, 1951

[3] C. F. von Weizsäcker, 'Die Rotation kosmischer Gasmassen', *Z. Naturf.*, 1948, 3A, 524

[4] J. A. Ratcliffe, 'Radio astronomy', *Proc. roy. Inst. G.B.*, 1952, **35**, 211

[5] Paneth, *Nature*, 1953, loc. cit.

[6] S. F. Singer, 'Meteorites and Cosmic Rays', *Nature*, 1952, **170**, 728

[7] L. L. Whyte, 'Fundamental Physical Theory', this *Journal*, 1951, **1**, 303

[8] J. Cockcroft, 'Experiments with high energy nucleons and quanta', *Proc. roy. Inst. G.B.*, 1952, **35**, 185

[9] J. Stebbins and A. E. Whitford, referred to by Gamow, 1952 (see above, p. 198)

Atomic and Isotopic Abundances. If some galaxies were recently formed from continuously created matter they should contain a large H/He ratio, while in those of greater age this should decrease. McKellar[1] observed that the C^{13}/C^{12} ratio is much higher in certain stars than on the earth. This variation is still inexplicable.

In conclusion, we may note that the elimination of rival theories using information from widely different fields is becoming feasible. Theories not disproved will consequently cover more data, co-ordinating harmoniously a widening range of astronomical, physical and geophysical observations. We associate the time parameter, whether finite or infinite, in our theories with the intuitive concept of 'the age of the universe'. Unless or until the linear extrapolation on the recession hypothesis be disproved, it will remain acceptable both as the simplest interpretation of the observations and as being in excellent numerical accord with the age from independent investigations. In preferring meanwhile to accept time invariant spectral frequencies and linear time scales, neither cosmological repulsion nor continuous creation, we are taking up the position of Lady Windermere:

'Lord Darlington: I think life too complex a thing to be settled by these hard and fast rules.
Lady Windermere: If we had these 'hard and fast' rules, we should find life much more simple.
Lord Darlington: You allow of no exceptions?
Lady Windermere: None!'

King's College
London, W.C. 2

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[1] A. McKellar, 'Intensity measurements on the main and isotopic carbon bands in the spectra of R-type stars', *Publ. astr. Soc. Pacif.*, 1947, **59**, 186

THE AGE OF THE UNIVERSE

ERNST J. ÖPIK

FIFTY years ago the concensus of scientific opinion was apparently in favour of a Universe without beginning or end. Of course, there was the second law of thermodynamics, according to which the Universe is steadily running down towards a state of equalisation ; but this law is not bound to any time-rate, and, unless actual processes were specified, could not be used to set definite time-limits. Further, its applicability to the Universe as a whole and to unlimited intervals of time was questioned.

More recently a change in the outlook has taken place. The recession of the extragalactic nebulae and radio-activity suggested that there was a beginning a few thousand million years ago, and a stage was visualised at which the Universe was packed together closely enough to cause the building up of the unstable radio-active isotopes.

In one view this stage was merely one beyond which extrapolation from the present state is not possible, and not necessarily an absolute beginning. The concept of age is thus reduced to that of a time-scale, or a time interval during which the properties of the Universe have radically changed.

Another view preferred the concept of an absolute beginning. The definition of the time-scale remained the same ; but the initial stage, a singularity, was the limit of extrapolation not only from the present, but from any state of the Universe, however close to the initial stage.

The difference between the two viewpoints is one of principle, unaffected by the particular model chosen to represent the initial state of the Universe. It applies equally to Eddington's primeval nebula and Lemaître's atom.

In the following review we will be guided by the principle of minimum hypothesis, which rules that new laws of nature must not be advocated for the explanation of facts which can be accounted for by known laws. A theory not supported by facts is a mere possibility ; it is only by chance that it may prove to be correct.

The fundamental fact in support of a short time-scale was, and remains, the red-shift of the extragalactic nebulae interpreted as a recession. The Hubble-Humason law (1928) of proportionality of red-shift to distance led to the fixing of the time-scale at a small multiple of 10^9 years. The result clashed with the then favoured time-scale of some 10^{12} or 10^{13} years, which was based chiefly on the theory of statistical equilibrium of stellar motions and orbits of binaries as developed by Jeans. The tug-of-war between the long and short time-scales can be regarded as concluded definitely in favour of the latter. Jeans' theory was correct, but it could not be applied to the stellar universe which is not in statistical equilibrium.

In the course of the controversy arguments based on subordinate time-scales were put forward, supporting the short time-scale of the Universe. An early account states [1] : '. . . the combined evidence . . . points to an age of the stellar universe of the same order of magnitude as the currently accepted age of the solar system : not much more than 3,000 million years.' Subsequent reviews arrived at practically similar conclusions.[2]

The Evidence

(*a*) *The Age of the Earth.* The continental shields represent the oldest undisturbed portions of the Earth's crust, and radio-active determinations have yielded high values of age for some minerals from these shields. Pegmatites from northern Karelia gave an average age of 1,950 million years.[3] Lead isotope determinations for pegmatites from south-east Manitoba indicate an age of 2,100 million years ; [4] for the same an average rubidium-strontium age of 2,240 million years results.[5] The Manitoba pegmatites are associated with granitic intrusions into older rocks which reveal traces of a long previous geological history. It appears to be safe to assign a lower limit of 2.5×10^9 years for the Earth's crust as well as for the solar system ; the formation of the planets and of the Earth's crust have taken relatively short intervals of time.[6]

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[1] E. Öpik, *Pop. Astr.*, 1933, **41**, 79 ; Harvard Reprint 84

[2] H. N. Russell, *Science*, 1940, **92**, 19 ; B. J. Bok, *Observatory*, 1936, **59**, 76 ; Harvard Reprint 122 ; S. Chandrasekhar, *Science*, 1944, **99**, 133 ; B. J. Bok, *Mon. Not. R. astr. Soc.*, 1946, **106**, 61 ; Harvard Reprint 284 ; H. Shapley, *Amer. J. Sci.*, 1945, **243**-A, 508

[3] L. H. Ahrens, *Nature*, 1947, **160**, 874

[4] A. O. Nier, *Phys. Rev.*, 1938, **55**, 153 ; *Phys. Rev.*, 1941, **60**, 112

[5] Ahrens, op. cit.

[6] cf. Harold Jeffreys, *The Earth*, 3rd ed., Cambridge Univ. Press, 1952

A method of extrapolation applied by Holmes,[1] based on the correlation between the original rock-ore abundances of the isotopes of radiogenic lead for different samples used in groups of more or less similar age, gave 3,350 million years for the age of the Earth, or the time during which radiogenic lead was produced in its materials. Jeffreys[2] pointed out the weakness of the calculation, which greatly depended upon the use made of a few discrepant values. Other determinations are: 2,900; 3,500; 2,100 million years.[3] It seems that 3×10^9 years can be provisionally accepted as a working basis.

(*b*) *The Age of the Elements.* Conditions leading to the formation of radio-active isotopes will throw the rest of the elements into a melting pot, too. According to an idea of Russell,[4] a maximum age for the elements can be obtained from the relative terrestrial abundance of a radio-active isotope and its end-product. The upper limit of age of the terrestrial elements thus found equals $5 - 6 \times 10^9$ years.[5] The lack of knowledge about the composition of the Earth's interior is hardly significant as the abundance ratio varies exponentially with time.

Although the relative abundances of the elements (excluding the lightest) on the Earth and in the atmospheres of the Sun and most stars are very similar, this does not necessarily mean a simultaneous origin for their elements. Only a similar mode of origin is implied.

There are several theories explaining the origin and abundances of the elements by equilibrium conditions inside superdense stars (Klein, Beskow, and Treffenberg; Hoyle; van Albada). Supernova explosions inject the mixture into space, whence it condenses again into new-born stars. Observations of the Crab Nebula,[6] a former supernova, suggest that the product of explosion—the amorphous core of the nebula—is poor in hydrogen, whereas its hydrogen fringe appears to be interstellar gas pushed ahead of the expanding core. We thus may have a double origin for the elements: hydrogen already present in space with an unknown original content of other elements; and the heavier elements enriching the mixture through supernova explosions. Old stars—those of Population II—show, indeed, a smaller metal content than those believed to be more recently formed,[1] suggesting a gradual change in the composition of the medium of which stars are built. If this is so, we need not go to the beginnings of the Universe to account for the radio-active isotopes on Earth : they may be products of supernova explosions that preceded the formation of the solar system.

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[1] A. Holmes, *Nature*, 1946, **157**, 680; 1947, **159**, 127; 1949, **163**, 453

[2] H. Jeffreys, *Nature*, 1948, **162**, 822; 1949, **164**, 1046

[3] F. G. Houtermans, *Z. Naturf.*, 1947, **2a**, 322; C. B. Collins, R. D. Russell, and R. M. Farquhar, *Canad. J. Phys.*, 1953, **31**, 402; A. P. Vinogradov, I. K. Zadoroshny and S. I. Zykov, *Acad. Sci. U.S.S.R.*, 1952, **85**, 1107

[4] H. N. Russell, *Proc. Roy. Soc. A*, 1921, **99**, 84

[5] A. Holmes, *Smithson. Inst. Rep.*, 1948, 227; Collins and others, op. cit.; Vinogradov and others, op. cit.

[6] W. Baade, *Astrophys. J.*, 1942, **96**, 188

On the other hand, a semblance of the observed abundances can also be obtained from a non-equilibrium building-up of the elements at an early stage of an exploding Universe (Alpher, Bethe, Gamow). The radio-active age limit might in this case apply to the Universe. The question remains open at present.

(*c*) *Meteorites.* The production of helium in meteorites by cosmic rays[2] is now an established fact, as otherwise the presence of the isotope He^3 in considerable amounts (18-32 per cent of He^4) cannot be explained.[3] For each three He^3 atoms cosmic rays should produce about ten He^4 atoms. This ratio being given, an analysis by the mass spectrograph leads to the determination of the amount of purely radiogenic He^4. As a result, the estimated ages of meteorites are greatly reduced and, from the provisional data available, hardly attain 1,000 million years. Meteorites bear testimony, perhaps, to catastrophes which took place in the solar system well after its formation, or it may be that they lost part of their helium when passing near the sun.

(*d*) *The Ages of the Stars.* There is little doubt that main-sequence stars rely upon the conversion of hydrogen into helium as their energy source. Sirius, of spectrum A0, spends 13 times more energy per unit mass than the Sun, consuming thus 13 per cent hydrogen by weight in 10^9 years. With 60 per cent hydrogen originally, the store of energy would last 4.6×10^9 years. There is probably not much mixing in stars outside their central regions (Öpik, Sweet) ; therefore, only about 25 per cent of the fuel is available, and the life-time of Sirius becomes 1,150 million years. It may then become a giant,[4] and ultimately collapse—possibly by throwing off its outer shell in a supernova explosion, leaving behind a white dwarf. The success in calculating composite models of red giants,[1] as well as Trumpler's classification of star clusters, lends support to this concept of stellar evolution. The more massive B stars will have a life-time of a few hundred million years only. This being much shorter than the life-time of the Galaxy, which cannot be younger than the Earth, it is concluded that the early-type stars are currently replaced by new stars condensing out of diffuse matter.[2] Where diffuse matter is no longer available, early-type stars are absent and only giants remain, as is actually observed in globular clusters. Using Baade's terminology,[3] Population II of the globular clusters, the Galactic Centre, and the general galactic background consists of aging members born at a remote epoch ; whereas Population I, connected with the diffuse matter and spiral structure, contains young early-type stars steadily coming into being and dying, in addition to the background of less massive young and old stars.[4]

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[1] M. Schwarzschild and L. Spitzer, *Observatory*, 1953, **73**, 77

[2] C. A. Bauer, *Phys. Rev.*, 1947, **72**, 354 ; 1948, **74**, 225, 501 ; H. E. Huntley, *Nature*, 1948, **161**, 356

[3] F. A. Paneth, P. Reasbeck, and K. I. Mayne, *Geochim. et cosmoch. Acta*, 1952, **2**, 300

[4] E. Öpik, *Publ. Astron. Obs. Tartu*, 1938, **30**, No. 3

The absence of normal B — A stars from the globular clusters sets their age at more than 1,500 million years.

The energy source of the giants remains a puzzle. Taking their persistent appearance in globular clusters as an indication of longevity, a more powerful source of energy must be assumed for their maintenance.[5] On the other hand, these giants may represent short-lived objects in statistical equilibrium—those which blow up or collapse being replaced by others becoming giants. This latter concept would agree with the calculated red-giant models[6] which are supposed not to draw on unknown sources of energy and are short-lived, their luminosities being abnormally high as compared with their masses. The giants of the globular clusters, as well as the short-period variables which should represent a phase preceding the giant stage, would then correspond to stars of more or less similar mass for which the exhaustion of hydrogen has reached a critical limit.[7] Taking the observed luminosities with Schwarzschild's models the limiting mass would be from 2.0 to 3.0, indicating for the clusters an age of from 8×10^8 to 2.5×10^9 years.

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[1] J. B. Oke and M. Schwarzschild, *Astrophys. J.*, 1952, **116**, 317 ; A. R. Sandage and M. Schwarzschild, *Astrophys. J.*, 1952, **116**, 463

[2] Öpik, op. cit.

[3] W. Baade, *Astrophys. J.*, 1944, **100**, 137

[4] cf. H. N. Russell, *Publ. astr. Soc. Pacif.*, 1948, **60**, 202

[5] Öpik, op. cit.

[6] Oke and Schwarzschild, op. cit.

[7] Öpik, op. cit.

The fork-shaped *H-R* (Hertzsprung-Russell) diagram of the globular clusters represents apparently the result of aging, in contrast to the continually-rejuvenated Population I of our surroundings (the difference in metal content having only a secondary effect). The globular clusters oscillate on both sides of the galactic plane with a period of less than 10^8 years. While passing for the first time through the plane, they must have been stripped of all their diffuse matter—which could have been only loosely bound by a gravitational potential of $\frac{1}{1000}$ that of the Galaxy—through collision with the diffuse matter near the galactic plane.[1] This would have prevented the subsequent formation of new stars in them. The stellar population of the globular clusters thus represents one of the oldest time-indicators of the Galaxy. The lower branch of their *H-R* fork appears to join the *H-R* diagram of Population I at absolute bolometric magnitude $+2$;[2] this should be the luminosity of old stars which have now arrived at the end of their career as dwarfs.

Their luminosity must have become, at this stage, about 0.5 mag brighter than the 'normal',[3] and would correspond to a mass of 1.7. The total duration of the dwarf stage at this mass would be around 4×10^9 years. This can be accepted also as an estimate of the age of the Galaxy.

The energy source of white dwarfs can consist only in the thermal agitation of atomic nuclei;[4] from this their age can be calculated. The highest values obtained equal $10^{11}/A$ years, A being the mean atomic weight. Considering that before the degenerate stage is reached triple collisions will convert all the helium into carbon, and then into heavier elements,[5] an average of $A = 20 - 30$ can be assumed; whence the age of the oldest white dwarfs equals 3 to 5×10^9 years. This may be near to the age of Population II and of the Galaxy.

(*e*) *Dynamical Stability of Star Clusters and Double Stars.* Most of the galactic clusters will dissolve either under the tidal action of the Galactic Centre or through encounters with field stars or other members of the cluster, in time intervals of the order of 10^9 years.[6]

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[1] cf. L. Spitzer and W. Baade, *Astrophys. J.*, 1951, **113**, 413

[2] Baade, op. cit., Fig. I

[3] E. J. Öpik, *Proc. Roy. Irish Acad.*, 1951, **54** A, 49

[4] L. Mestel, *Mon. Not. R. Astr. Soc.*, 1953, **112**, 583

[5] Öpik, op. cit.

[6] B. J. Bok, *Harvard Circ.*, 1934, no. 384; S. Chandrasekhar, *Astrophys. J.*, 1943, **98**, 54

Although this refers to the future and is compatible with an unlimited past, the probability of simultaneous occurrence of a great number of old clusters which just now have come to the verge of disruption is very small. We may assume, therefore, that the age of most clusters is some 10^9 years or less. On the other hand, most of them contain early-type stars which cannot be very old. Consideration of the dynamical stability of clusters confirms the youth of their members, and adds another argument in favour of the theory that stars are being born continually. Apart from that, no new criterion of age for the Galaxy is forthcoming : clusters which are older than their stellar content cannot be observed.

The position is similar with wide double stars. The distribution of the distances between their components [1] indicates that equipartition of energy cannot have taken place,[2] and that the binaries could not have been subjected to encounters with field stars for longer than, say, 5×10^9 years.[3] On the other hand, the statistical material from which this conclusion is drawn is based chiefly on the relatively luminous A-type binaries which, according to the preceding, cannot have lived to so great an age.

Thus, conclusions as to age based on the dynamical stability of clusters and double stars are overruled by the shorter life-time of their components, and can be used only to re-affirm the short time-scale of stellar evolution.

(*f*) *The Red-Shift.* The observations by V. M. Slipher, Hubble, and Humason, if interpreted in a straightforward manner, indicate an expansion of the visible portion of the Universe.

Recent developments have shown that Hubble's scale of distances should be at least doubled. The distances of the nearest nebulae were determined by Hubble from the period-luminosity relation of the long-period cepheids. The zero-point of this relation depended upon space-absorption in low galactic latitudes and was known to be inaccurate. Some cosmological theories actually depended upon the resulting scale of distances, and the unexpectedly large correction in the scale is a shock to all theories involving the so-called cosmological constant. From the standpoint of economy of thought, the cosmological constant (equivalent to a repulsion) must be suspended from active duty for the time being.

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[1] E. Öpik, *Publ. Astron. Obs. Tartu*, 1924, **25**, no. 6 ; G. P. Kuiper, *Astrophys. J.*, 1942, **95**, 212

[2] V. A. Ambarzumian, *Nature*, 1936, **137**, 537

[3] S. Chandrasekhar, *Science*, 1944, **99**, 133

Within the Galaxy a more reliable criterion of distance is offered by the cluster-type variables. The average luminosity of these high-velocity objects does not so much depend upon space-absorption and is well determined. They were too faint to be observed in the nebulae by Hubble. Now cluster-type variables have been found in the Magellanic clouds,[1] but about 1.3 mag fainter than expected from the magnitudes of the long-period cepheids. Thus, the long-period cepheids are 1.3 mag brighter and all distances based on them 1.8 times greater than formerly assumed. The apparent diameters and integrated luminosities of globular clusters in external galaxies call for a similar correction.[2]

This, however, is not the whole story. The recession constant of the nebulae depends entirely on the more distant objects whose distances were linked to the cepheid scale of the nearer galaxies through intermediate criteria : the magnitudes of the brightest stars and of the nebulae themselves. Both criteria are of a statistical nature and not only involve photometric errors, but depend upon the true dispersion of the magnitudes ; the dispersions, and therefore the distances, seem to have been underestimated by Hubble. A comprehensive survey of the problem has been given by Behr.[3] He concludes that those of Hubble's intrinsic luminosities of the nebulae which are not based on variable stars should be increased by 1.7 mag. This correction must be added to that of the cepheid zero-point, the total amounting to 3.0 mag, or an increase in the distances of nebulae (except the nearest, which are based on cepheids) in a ratio of 4 to 1. The constant of recession now becomes 145 km/sec. per megaparsec. The expansionistic time-scales are increased four-fold, and even the shortest will yield more than the lower limit—the age of the Earth. The retention of the cosmological constant by Eddington and Lemaître was justified by the need to extend the time-scale ; the slow phase of expansion, when attraction and repulsion nearly balanced each other, allowed this to be done almost indefinitely. Now, with the increased distances, cosmic repulsion becomes a superstructure of a purely aesthetic nature.

Without the cosmological constant, the Friedmann-Einstein cosmological models[4] are best suited to deal with the expanding universe. All depends now on its, as yet unknown, average density.

[1] A. D. Thackeray and A. J. Wesselink, *Mon. Not. astr. Soc. S. Afr.*, 1953, **12,** 33 ; *Nature*, 1953, **171,** 693

[2] H. Shapley, *Sky and Telescope*, 1952, **12,** 45

[3] A. Behr, *Astr. Nachr.*, 1951, **279,** 97

[4] cf. P. Couderc, *The Expansion of the Universe*, London, 1952

Zwicky[1] finds considerable amounts of matter in the space between the galaxies, and favours an average density of some 10^{-26} gm./cm.^{3} The clusters of galaxies, in which considerable internal motions are observed, are apparently held together by gravitation. In such a case the virial theorem leads to a determination of mass and density. For the Virgo cluster a mass of $5 \times 10^{11} \odot$ per nebula including intergalactic matter results.[2] With 12 nebulae per cubic megaparsec[3] the density becomes $\rho = 4 \times 10^{-28}$ gm./cm.^{3} This figure refers to Hubble's scale of distances. With the new scale, the volume is 64 times, the dynamical mass 4 times greater, and the world density is $\rho = 2.5 \times 10^{-29}$ gm./cm.^{3} With this, and the expansion constant in relativistic units, $H = 1.56 \times 10^{-28}$ in the new scale, the Freidmann-Einstein criterion becomes[4]

$$\tfrac{1}{3}\kappa\rho - H^2 = 1.57 \times 10^{-56} - 2.43 \times 10^{-56} = -0.86 \times 10^{-56}.$$

This would mean negative curvature, an open and infinite space. However, allowing for the uncertainty in density, both closed and open space is possible, in which case the time of expansion will not differ much from that for uncurved space, and becomes

$$t = \frac{2}{3Hc} = 4.5 \times 10^9 \text{ years},$$

the limits of uncertainty being, perhaps, from 3 to 6×10^9 y.

This would represent the time elapsed since the Universe was in a highly condensed state. This state cannot yet be described. The theory of the origin of the elements, as shown above, does not provide a clue. The same is true of the cosmic rays, which appear to be of stellar origin and whose connection with the pre-stellar stage of the Universe seems to be improbable.[5]

(*g*) *Space-Reddening of Galaxies.* This phenomenon, consisting in an increase of the colour index of distant galaxies, not accounted for by the red-shift,[6] led to far-reaching speculations on observable effects of stellar evolution. The effect seems to be restricted to elliptical nebulae (Population II), as spirals do not show reddening.[7]

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[1] F. Zwicky, *Publ. astr. Soc. Pacif.*, 1952, **64**, 247

[2] B. J. Bok, *Mon. Not. Roy. astr. Soc.*, 1946, **106**, 61 ; Harvard Reprint 284

[3] A. Fletcher, *Mon. Not. Roy. astr. Soc.*, 1946, **106**, 121

[4] Couderc, op. cit.

[5] L. Biermann, *Ann. Rev. Nucl. Sci.*, 1953, **2**, 335 ; T. G. Cowling, *Le Champ Magnétique de la Galaxie*, Conference at Liège, May 19, 1953

[6] J. Stebbins and A. E. Whitford, *Astrophys. J.*, 1948, **108**, 413

[7] A. E. Whitford, *Astron. J.*, 1949, **54**, 138

A study by Vaucouleurs[1] seems to have been overlooked. He proved that the effect is due to the depression in the ultra-violet produced by absorption lines. With the red-shift the ultra-violet depression is displaced into the blue, making the blue-red colour index redder. The writer of the present essay checked Vaucouleurs' claim and convinced himself of its validity. As to the spirals, they show a considerable amount of emission,[2] which will fill the ultra-violet depression. The absence of the reddening for spirals is thus explained without invoking stellar evolution.

(*h*) *Alternative Hypotheses.* It has been repeatedly stressed that the nebular red-shift may not indicate recession, and alternative suggestions have been made recently (Freundlich, Shelton). It is difficult to imagine a collisional process of reddening without simultaneous blurring of the nebular images.[3] Further, the non-expanding Universe will be unstable and will end in collapse; or in expansion, if the cosmological repulsion is introduced. Thus, the present state would be exceptional, the normal state being one of Doppler shifts corresponding to real approach or recession. It does not seem advisable to sacrifice the solid concept of recession to a piling-up of *ad hoc* new laws and improbable states.

Continuous creation of matter (R. O. Kapp, P. Jordan, H. Bondi, T. Gold, F. Hoyle) is another alternative which would dispense with a finite age for the Universe. It requires the retention of the cosmological constant. These theories can at present be assessed only from the standpoint of their aesthetic value. It is not easy to imagine observational criteria for them which cannot be explained away. Perhaps the distribution of masses of the galaxies can provide a proof. Galaxies will grow by accretion, especially large ones with gaseous envelopes firmly bound by gravitation, through catching atoms from intergalactic space or incorporating whole gaseous envelopes of smaller galaxies.[4] They will grow almost indefinitely with time. Their frequency per unit volume in Hoyle's universe will vary inversely as the cube of age, thus more or less as the cube of mass, too; when selected by apparent magnitude, there will be no upper limit of mass and almost no correlation of distance with magnitude. The available evidence implies a frequency of nebulae in space decreasing with the

[1] G. de Vaucouleurs, *C. R. Acad. Sci.*, 1948, **227**, 466

[2] Thornton Page, *Astrophys. J.*, 1952, **116**, 63

[3] R. D'E. Atkinson, *Observatory*, 1953, **73**, 159

[4] cf. L. Spitzer and W. Baade, *Astrophys. J.*, 1951, **113**, 413

4/3 power of mass,[1] a definite upper limit of mass,[2] and a correlation of distance with apparent magnitude. Although rudimentary, the evidence is definitely negative.

Conclusion

The rate of irreversible processes in different physical complexes—the radio-active elements, the Earth and the solar system, the stars, stellar systems, the Galaxy, the observable portion of the extra-galactic universe—is such as to suggest an age not exceeding 6,000 million years for the Universe in its present form and content. The extra-galactic nebulae, with our Galaxy and its backbone of Population II, may have been formed some 4,500 million years ago, the Sun as a star of Population I coming into being perhaps later.

Cosmological repulsion is not necessarily required by the existing observational evidence. The same is true of the continuous creation of matter and the alternative interpretations of the nebular red-shift; these are mere possibilities, serving the purely aesthetic purpose of denying the Universe a temporal origin.

The observed velocities of recession exceed one-fifth of the velocity of light, the energy corresponding to a packing fraction of 0.02 per nucleon. Nothing short of an explosion from the densest-known state of matter—nuclear fluid—could be advocated as the cause. Our knowledge of the present density of matter in the Universe is insufficient to decide between the two possibilities: that of open space, in which the whole Universe is an irreversible process of temporal origin; and that of closed space, in which the Universe may return to its initial state, implying oscillations—the collapsing Universe rebounding from the elastic forces of the nuclear fluid at a state of maximum compression.[3]

In the first case the possibility exists that what we observe now is merely the Metagalaxy—only a step in the hierarchy of physical systems. The finite intensity of the sky background cannot serve as an objection to the concept of an unlimited Universe built on an hierarchical principle (C. V. L. Charlier).

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[1] E. Holmberg, *Medd. Lunds Astr. Obs.*, 1952, S. I., No. 180; F. Zwicky, *Publ. astr. Soc. Pacif.*, 1951, **63**, 61

[2] Page, op. cit.

[3] The collapsing gaseous Universe, once it has passed the stage of the building up of heavy elements out of hydrogen, will have a ratio of specific heats less than 4/3 on account of radiation and nuclear dissociation, and cannot cease collapsing while gaseous.

In the second case the whole Universe, i.e. all its energy content, including radiation, returns to the initial state of nuclear fluid. The Universe is oscillating without external loss ; entropy increases during expansion, decreases during contraction. The oscillation could imply an unlimited age of the Universe in the past and in the future,[1] a repetition of its structural phases without, however, an ' eternal recurrence of all things ' in Nietzsche's sense : the individual celestial bodies in successive phases would not be identical, nor would their inhabitants.

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[1] Time is here considered irrespective of its algebraic symbolics and numerical value, and means simply a succession of events.

THE AGE OF THE UNIVERSE

G. J. Whitrow

> What did God before He made heaven and earth ? I answer not as one is said to have done merrily, eluding the pressure of the question, 'He was preparing hell (saith he) for pryers into mysteries '.
>
> *Confessions of St Augustine*, XI, 14.

1 *The Logical Aspect of the Problem*

Since the dawn of philosophy, and especially since Zeno of Elea first formulated his famous paradoxes, the concept of time has never ceased to intrigue and puzzle those who think deeply. In particular, the problem of the temporal origin of the universe has both fascinated and bewildered philosophers of nature. Before we can properly discuss this problem in the light of modern knowledge we must first consider whether the concept itself has a meaning.

If we examine a particular Chinese vase we may not know when it was made nor be sufficiently expert to deduce that it is a typical product of the Ming dynasty, but few would stop to dispute the meaningfulness of the question 'When was it made ? ' If we were able to study the protons which form part of the vase we might ask 'When were these protons made ? ' Although we could not be sure whether they were ever ' made ', e.g. by the decay of neutrons in free space at some remote epoch, we still would be unlikely to dispute that this question too has a meaning. When, instead, we come to consider whether the whole physical universe had a temporal origin then we soon realise that the question is of a different status from our former queries.

The root difficulty concerning the meaningfulness of the question depends on the peculiar relation between the concepts ' universe ' and ' time '. This was clearly realised by both Plato and St Augustine. In Plato's cosmology space appears to have existed before time, but the universe and time were created together. The universe was fashioned by the creator in accordance with an ideal pattern which was eternal.

> But to bestow this attribute altogether upon a created thing was impossible; so he bethought him to make a moving image of eternity, and while he was ordering the universe he made of eternity that abides in unity an eternal image moving according to number, even that which we have named time.[1]

Similarly, St Augustine, who inherited the fruits of Greek philosophy as well as of Jewish theology, was led to ask: 'Seeing therefore that God, whose eternity alters not, created the world and time, how can he be said to have created the world in time, unless you will say that there was something created before the world, whose course time did follow?' And he answered: 'verily the world was made with time and not in time, for that which is made in time is made both before some time and after some.'[2]

Thus both Plato and St Augustine saw that the problem of the temporal origin of the universe involved the problem of the origin of time itself. That this question is of a different kind from that of the origin of a vase or a proton is immediately evident when we reformulate it in the transparently reflexive form 'At what time did time begin?' As McTaggart remarked in his famous essay on the unreality of time, 'time cannot be explained without assuming time',[3] and he argued that this implies either that the concept is invalid, as he himself believed, or else ultimate.

The logical paradoxes implicit in our question were clearly enunciated by Kant in the first of his four antinomies of pure reason. He argued that if the world had a beginning then it must have been preceded by an empty time. No coming-to-be is possible, however, in an empty time since no part of such a time can be distinguished from any other part, and 'no part of such a time possesses, as compared with any other, a distinguishing condition of existence rather than of non-existence; and this applies whether the thing is supposed to arise of itself or through some other cause.'[4] Instead of adopting Kant's conclusion that this argument shows that the world has no beginning, we can adopt the alternative answer of Plato and St Augustine, that the world and time co-exist. This solution is reinforced by Kant's own rejection of the conclusion that the world has no beginning. For, if we adopt it, then we are committed to the belief that up to every given moment there has passed away in the world an infinite series of successive states of things. ‘ Now ’, says Kant,

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[1] Plato, *The Timaeus of Plato*, ed. by R. D. Archer-Hind, London, 1888, 119-121

[2] St Augustine, *De Civitate Dei*, transl. by J. Healey, London, 1945, Book XI, Chapter VI

[3] J. McT. Ellis McTaggart, *Philosophical Studies*, London, 1934, 126

[4] Immanuel Kant, *Critique of Pure Reason*, transl. by N. Kemp Smith, London, 1934, 127

> the infinity of a series consists in the fact that it can never be completed through successive synthesis. It thus follows that it is impossible for an infinite world-series to have passed away, and that a beginning of the world is therefore a necessary condition of the world's existence.[1]

One of Kant's most severe critics has argued that his antinomies do not specially involve time (or, for that matter, space), since any other continuous series, including that of real numbers, raises the same problems. ‘ Kant's belief . . . in the existence of certain antinomies peculiar to space and time,’ contends Bertrand Russell, ‘ has been disproved by the modern realisation of Leibniz's universal characteristic.’[2] This is a very strange retort. The modern theory of infinity, to which Russell in fact appeals, is essentially a *static* theory of infinite sets. Similarly, the modern theory of the variable, as developed first by Weierstrass, is again a static theory, for the variable is no longer regarded by pure mathematicians as representing a progressive passage through all the values of an interval but the disjunctive assumption of any one of the values in the interval. Thus the acceptance of the modern theory of the continuum cannot be invoked as a valid argument automatically disposing of Kant's antinomies concerning time, since this theory has been developed by specifically omitting all previous intuitive reference to the concept of time. Kant's argument, in a modern setting and without reference to whatever Kant may have thought about infinite series and the mathematical continuum, survives Russell's criticism in so far as it refers to successive acts occurring in time.

Since the problem of a temporal origin of the universe is based on the concept of a time pertaining to the universe as a whole, it is convenient, at this stage, to introduce the term *cosmical time*. A universe in which there is no total change occurring has, strictly speaking, no cosmical time, and Kant's objection to its infinite past, therefore, no longer applies. It can be regarded as eternal since it is timeless. Parmenides' spherical universe is of this kind, and so is

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[1] Kant, *Critique of Pure Reason*, loc. cit.

[2] B. Russell, *The Principles of Mathematics*, London, 1942, 461

Einstein's static universe, in so far as we do not invoke any property of spontaneous ' decay ' of its constituent particles leading to its possible expansion (or contraction) in virtue of its ' instability '. Moreover, an eternal timeless universe need not necessarily be completely uneventful. St Augustine overstated his case when he argued ' Behold the heavens and the earth are ; they proclaim that they were created ; for they change and vary. Whereas whatsoever hath not been made, and yet is, hath nothing in it, which before it had not ; and that is to change and vary.'[1] Provided that all small-scale happenings in the universe are purely random and show no evidence of any preferred trend so that the universe *in toto* does not change or vary or show any preferential trend, we can legitimately regard it as eternal and timeless, unless we have some *other* evidence for its original creation or ultimate destruction.

Similarly, we can legitimately consider the possibility that there is a cosmical time provided that this time had a beginning. Such a time may reveal itself as a definite trend in the universe, for example, in a progressive change of the over-all spatial characteristics of the universe (expansion or contraction) or in the form of an ' evolutionary sign-post '. Kant's objection can, I believe, still be sustained against the concept of a cosmical time which is eternal in the sense of infinite progressive duration in a definite one-way direction from past to future. At least, it has not yet been properly refuted.

Before discussing the relevant empirical data, we must note that, although we cannot rule out the existence of a temporal origin of the universe on purely logical grounds, such an origin is not to be regarded as an ' event ' in the way in which subsequent happenings are events. Its rôle is somewhat analogous to that of a number which is the limit of a sequence although not itself a member of the sequence. Since, however, the notion of a sequence with a limit normally implies an infinity of terms approaching the limit, perhaps a better analogy can be drawn with the number zero considered in relation to the sequence of positive integers in descending order. Zero is the next quasi-integral number, one less than unity, but it is *not* a member of the sequence of positive integers. Similarly, world-creation cannot be regarded as an event in any way analogous to subsequent events.

This preliminary logical inquiry has thus shown that the concept of a temporal origin of the universe has a meaning provided that either the universe as a whole is essentially timeless, in which case there is no such origin, or else admits a one-way cosmical time with a definite origin.

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[1] St Augustine, *Confessions*, transl. by E. B. Pusey, London, 1942, Book XI, Chapter IV

2 *The Oldest Physical Objects*

In a famous lecture on cosmogony in 1871, Helmholtz argued that men of science are not only entitled but are beholden to investigate whether

> on the supposition of an everlasting uniformity of natural laws, our conclusions from present circumstances as to the past . . . imperatively lead to an impossible state of things ; that is, to the necessity of an infraction of natural laws, of a beginning which could not have been due to processes known to us.[1]

Considered as a question of science, this is no idle speculation for it concerns the extent to which existing laws are valid.

According to Archbishop Ussher, God created the world on Sunday, 23rd October, 4004 B.C.[2] Recent scientific attempts to date the remote past are much less precise. The complexities of the problem are now more evident than they once were. Nevertheless, in the light of the most recent knowledge two broad conclusions can be drawn : first, as we shall see, several independent lines of evidence, based on the analysis of empirical data concerning the origin of various physical objects, all tend to converge towards an era in the past some 4,000 million years ago ; second, this impressive agreement as regards order of magnitude sharpens the problem of the temporal origin of the universe so that we can now ask not merely whether there was such an origin, but more precisely whether the scale of past time is confined to a few thousand million years. I propose in the present section of this essay to survey very briefly the evidence bearing on the age of objects in the universe and to devote the final section to the consideration of the universe itself.

It is well-known that the most powerful method we possess for estimating the age of the Earth's crust is based on age determinations of radio-active minerals. The oldest known radio-active minerals are more than 2,000 million years old. In order to determine how much older than this the Earth is likely to be, Holmes, in 1946 devised a method depending on the fact that one of the isotopes of lead (Pb^{204}) is not known to be generated by any naturally radio-active element, whereas the other three are. While it cannot be assumed that primeval lead was free from these other isotopes, it is reasonable to assume that lead which contains the lowest proportion of them in relation to Pb^{204} is closest in composition to primeval lead. By selecting specimens of lead minerals of known age and isotope composition the separate variations of the radio-active isotopes could be plotted against time. The remarkable result emerged that, despite the uncertainties of the data, a fair proportion of the lines tended to cross at the same point from which a time-value could be read. As a result, Holmes claimed that the most probable age of the Earth's crust is 3,350 million years, and he argued that this was virtually the age of the Earth itself.[1] This conclusion has been disputed by Jeffreys who thinks that it may be a considerable over-estimate.[2]

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[1] H. Helmholtz, *Popular Lectures on Scientific Subjects*, Second Series, transl. by E. Atkinson, London, 1881, 144

[2] J. Ussher, *The Annals of the World Deduced from the Origin of Time*, London, 1658, 1

Apart from lead, we know that helium is generated by radio-active disintegration. Age estimates based on the determination of the amount of helium present suffer from an added uncertainty : for, since helium is a gas, it is more likely to escape than lead. Nevertheless the helium-method has been applied to the determination of the ages of meteorites by Paneth who argued that the results were fairly reliable since meteoric iron has an extremely high helium-retentivity.[3] The ages assigned by this method range up to about 7,000 million years, but may be over-estimates due to ignorance concerning possible primeval helium. Moreover, it is now thought that some of the helium present may be of cosmic ray origin. Consequently, it is by no means improbable that the upper age limit for meteorites will ultimately be scaled down to some 3,000 or 4,000 million years.

The radio-active method for determining the ages of the rocks has an immediate bearing on the age of the Sun. The amount of radiation received from the Sun cannot have varied by more than a few per cent at most since life has existed on the Earth. The oldest fossils occur in Cambrian rocks which are estimated to be some 500 million years old. Hence, we conclude that the Sun has existed in much the same state for at least that interval of time. The problem of its total age is best regarded as part of the wider problem of the ages of the stars. This problem depends essentially on the theory adopted to account for the generation of stellar radiation. The origin of this energy is now thought to be thermo-nuclear and to follow one or other of two possible processes, the carbon cycle and the proton-proton reaction. In either case the main feature is the conversion of hydrogen nuclei into helium nuclei. Consequently, a star cannot shine if it has consumed all its hydrogen, and indeed it may only be able to consume a fraction of its hydrogen. It is possible, on the basis of what are thought to be reasonable estimates of a star's primeval chemical composition and the observed rate at which it is radiating energy, to calculate its possible total life-time as a shining star. The calculations are not precise but they strongly suggest that the total lives of the so-called Main Sequence stars are of the order of thousands of millions of years and that the present age of the Sun and similar stars is probably of the order of 5,000 million years. The calculations are based on the assumption that the mass-luminosity law applies all the time, so that, since a star loses only a fraction of a per cent of its mass during the conversion of its hydrogen into helium, it radiates at the same rate throughout the process. Many stars deviate considerably from this law. Some radiate so prodigally that their ages, relatively speaking, must be very short. Others, notably the White Dwarfs, are underluminous; nevertheless, we are not obliged to infer correspondingly enormous ages for them as there is no reason to assume that they always were such feeble radiators in the past. Indeed, they may be burnt-out ex-prodigals.

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[1] A. Holmes, *Nature*, 1947, **159**, 127

[2] H. Jeffreys, *Nature*, 1948, **162**, 822

[3] W. J. Arrol, R. B. Jacobi and F. A. Paneth, *Nature*, 1942, **149**, 235

Not all stars exist in splendid isolation like the Sun. Groupings of stars are found ranging from binaries to vast clusters. External influences will tend to disrupt them. Theoretical calculations based on observational data have been made to estimate the possible life-times of these respective groupings. From calculations made by Ambartsumian it appears that the disturbing influence of the Galaxy on close binaries has not been acting for more than 10,000 million years at most. Estimates of the possible ages of the more open clusters confirm that this is an upper limit and that it can probably be reduced to a half or even less.

The rough estimates of age deduced from these geophysical and astronomical calculations are comparable with the result of a calculation of a very different type. It is well known that uranium occurs naturally in the world in small quantities. The commoner isotope has a half-period of about 4,500 million years. The conditions which we believe to be necessary for the formation of heavy nuclei do not appear to exist either in interstellar space, as we observe it today, nor in the interior of stars (according to current theories), with the possible exception of super-novae. Many physicists therefore take the view that the present survival of uranium in small but appreciable quantities is evidence that the past history of the universe is finite and that conditions were much more primeval some four or five thousand million years ago.

Finally, to conclude this bare summary of the relevant empirical evidence, we come to what is perhaps the greatest astronomical discovery of the past half-century, the red-shifts in the spectra of the extragalactic nebulae. Whereas all our previous data relate to physical objects in the universe, this discovery is thought by many to concern the universe directly as a whole. Its interpretation and any estimate of age which can be derived from it are therefore crucial for our problem. These questions will be considered in the following section, and the results of the investigations which have just been considered will, despite their individual uncertainties, function collectively as a welcome independent check.

3 *The Age of the Universe*

Careful study of the spectra of at least twenty extragalactic nebulae photographed with the aid of the 100-inch reflector at Mount Wilson has shown that the proportional shift, i.e. the ratio of apparent increase in wavelength to standard wavelength, is the same throughout the spectrum of a given nebula, to within the limits of observational error.[1] This property is a necessary, although not a sufficient, condition for interpreting the shifts as due to the Doppler effect associated with recessional motion. The associated velocities attain astonishingly high values, the largest recorded so far being about one-fifth that of light for two nebulae in the Hydra cluster. The magnitude of these attributed velocities has led many to question the validity of the hypothesis that the shifts indicate motion. In defence of the Doppler interpretation it may be pointed out that a nebula comparable to our own Galaxy when receding even with one fifth of the velocity of light will require a period of the order of half a million years to pass through a distance equal to its principal diameter, whereas the Earth in its orbital motion around the Sun performs a similar feat in under ten minutes! So far no alternative hypothesis suggested by known physical phenomena, e.g. gravitational influence or a pseudo-Compton effect, has anything like the intrinsic plausibility of the Doppler interpretation.[1] Moreover, the law of red-shifts, relating shift and apparent distance, if due to any cause other than motion, might be expected to operate for all galaxies, whereas Hubble has shown that, in fact, it does not appear to hold within the so-called local group to which our Galaxy belongs.[2] This can be most easily explained if we assume that the tendency to recessional motion is masked by proper motions in the gravitational field of the local group.

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[1] E. P. Hubble, private communication; see also O. W. Wilson, *Publ. astr. Soc. the Pacif.*, 1949, **61**, 132

At present the principal difficulty in analysing the red-shift phenomenon is the determination of a reliable scale of distance. Thus, until the autumn of 1952 a scale, due principally to Hubble, was generally accepted. Since then it has been superseded by another, due to Baade, which is approximately twice as large, e.g. the new distance assigned to the Andromeda nebula is about one and a half million light-years, as against seven hundred and fifty thousand light-years.[3]

Accepting the new scale and the recessional interpretation of the red-shifts, we find that in the law (often called Hubble's law) relating the distance r and the velocity of recession v of the nearer galaxies, $r = vt$, the value of t (a constant of the dimensions of time, the same for all galaxies) is about 4,000 million years.

One of the many difficulties with which we have to contend in studying the red-shifts is that we have no direct evidence of their behaviour in time. If, however, we assume that the apparent shift of each nebula does not change with lapse of time, then its relative motion (on the Doppler interpretation) will be uniform. If the shift does change then its relative motion will correspondingly increase or decrease with time. Adopting the hypothesis of temporal uniformity of shift, we deduce that the nebulae must all have been compressed together in a comparatively small volume at some four thousand million years ago. Taken in conjunction with the data of the previous section we have an impressive body of evidence pointing to the profound significance of this interval of past time.

The case for interpreting this interval as the age of the universe is considerably strengthened when we take due account of the peculiar angular distribution of the nebulae in the sky. At first sight they appear to be distributed most unevenly, but even if we neglect small-scale irregularities there is still an apparent zone of avoidance flanking the Milky Way. This effect is attributed to the strong concentration of interstellar obscuring matter towards the central plane of the Milky Way, and if this is allowed for, the system of galaxies, unlike the stellar system, is found to be more or less isotropically distributed in the sky and with no sign of any thinning out with depth. Unless and until we have good reason for qualifying this conclusion, it constitutes the most impressive direct evidence that the system forms the background of the whole physical universe. By invoking the theory of relativity it can be shown that the centrality of our own Galaxy is purely apparent and that, roughly speaking, the same world-picture could in principle be seen from any other galaxy. Combining these conclusions with the Doppler interpretation of the red-shifts, we find that the whole universe is expanding from a primeval state of maximum concentration some 4,000 million years ago.

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[1] R. d'E. Atkinson, *Observatory*, 1953, **73**, 159

[2] E. P. Hubble, *J. Franklin Inst.*, 1939, **228**, 131

[3] W. Baade, *Trans. int. astr. Un.*, **8**, Cambridge (in the press)

It has been suggested, however, that the recessional interpretation of the red-shifts, even when combined with the hypothesis that the extragalactic nebulae form the cosmical background, does not necessarily imply that the universe itself is expanding. We can still have a cosmical steady state provided we accept the hypothesis of a continual statistically uniform creation of new matter, e.g. in the form of hydrogen molecules, *ex nihilo*. The rate of creation must just balance the effect of expansion. Such a universe, it is claimed, would be cosmically timeless and there would be no world-evolution.[1]

Against this ingenious theory the following objections *inter alia* can be brought. First, the alleged rejection of cosmical time is only partial, for the universe still possesses a temporal trend since the evolution of its constituents is a one-way process. Consequently, since there is a definite time direction signpost, the postulated eternity of this universe is not mere world-changelessness but implies an infinite past (and future) duration, a conception which we have seen is still open to Kant's criticism. Also, the parameter t in Hubble's law is no longer a measure of the age of the universe, but combined with the local world-density determines the required rate of creation of new matter. The fact that t is of the same order as the various age estimates discussed becomes an inexplicable coincidence. Furthermore, evidence has recently been found suggesting that this theory is in direct conflict with observation. It has been known since 1948 that distant elliptical nebulae show ' excess reddening ' in the distribution of their light-intensity, over and above the reddening corresponding to their observed red-shifts, and that this excess increases with distance. On the steady-state theory the *intrinsic* light-characteristics of distant nebulae must be the same *statistically* as those of nearby nebulae, and so this excess reddening is ascribed to the effect of intervening absorbing matter. Recently, however, Whitford has found that distant spiral nebulae instead of showing a similar excess reddening, as they should do on this theory, are actually ' very blue '.[1] The excess reddening of ellipticals and blueing of spirals thus appear to be intrinsic : we see the various distant nebulae as they respectively were at an earlier stage of cosmical evolution. If Whitford's work is confirmed, the steady-state theory will have to be rejected.

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[1] H. Bondi and T. Gold, *Mon. Not. R. astr. Soc.*, 1948, **108**, 252

Thus, although we can give no final answer to the vast problem of the temporal origin and age of the universe, we now stand at a much better vantage point than Helmholtz in 1871 when he delivered his lecture on cosmogony. Although it is still just as true now, as Helmholtz remarked then, that no hypothesis concerning the origin of the world can be verified by direct observation, many independent lines of inquiry now show a general tendency to converge towards the same epoch in the past. This remarkable convergence is itself the best answer to those who are sceptical of the ' hair raising extrapolations ' involved in each separate investigation, and it strongly suggests that the universe has a finite age of some 4,000 million years.

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[1] A. E. Whitford, *Astr. J.*, 1953, 58, 49

THE AGE OF THE UNIVERSE

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Introduction. The desire to know when the world began is one that arises with man's speculations on the primary questions concerning his existence. To realise that there is repetition and succession of generations is also to ask, 'When was the first?' An awareness of long run changes in the earth's surface, as taught by geology, and in the plants and animals of the earth, as taught by paleontology and biology, carries the question from the origin of man to the origin of the earth and its creatures. But, beyond the earth, astronomy too has found evidences of change, as far in the universe as telescopes have reached. The question of 'When did it start?', asked for man and the natural world immediately about him, does eventually lead to the question of 'when?' for the entire universe.

We will begin by discussing to what extent we may justifiably consider the age of the universe in terms of the time units which we use in our contemporary time reckoning. We shall then discuss some of the suggestions for the age of the universe which have emerged from physics and astronomy in recent years. A further and primary question is whether or not there is any meaning at all to the concept 'age of the universe'. In order of logic this question probably should be treated first, but we shall postpone it to the last, and before treating it will assume that the concept of age of a process, as used in physics and every-day life, has a meaning even as applied to the universe.

Units of Time. The passage of time is customarily measured in terms of some cyclic, repetitive process; the duration of a non-cyclic process is determined by observing how many of the measuring cycles occur between the beginning and end of the process. The first cycle to be used as a clock must certainly have been the revolution of the earth on its axis, and the more sophisticated time-keeping devices of contemporary life have no difference in principle from the cycles, like the axial or orbital revolution of the earth, which are obviously presented in nature. All units of time are defined by reference to a physical process, and any given period of time, expressed in chosen units, is identical with the time required for an equivalent number of those physical processes in terms of which the time units that are used have been defined. There is, then, a directly physical basis for both our units and our measurements of time.

The time-unit which is used in discussing the age of the universe gains its status as a standard from the process in terms of which it is defined. If the age of the universe is given as being *N* years, the statement is being made that during the period of existence of the universe the process of the earth's rotation about the sun would have taken place *N* times, in a solar system precisely like the contemporary solar system which we know and in terms of which the year has been defined.

Time and Physical Laws. The constancy of ratio between the period of the earth's orbital rotation and the period of other kinds of uniform cycles is sufficiently obvious that in the ordinary time reckonings of history we do not question the validity of the year as a time standard. However, during the period that spans the entire existence of the universe there may have been changes in the laws of nature themselves, and as a result there may have been changes in relations between the time of an orbital revolution of the earth in a prescribed solar system and the time of other cyclical processes of nature. This possibility of changes in fundamental physical relations has obvious relevance for the problem of the age of the universe.

Proposals for time changes in physical processes have been made by, among others, P. A. M. Dirac and the late E. A. Milne. Dirac's suggested cosmology, for example, requires that the Newtonian gravitational constant *G* vary with time, being proportional to the reciprocal of the age of the universe. The dynamical characteristics of a prescribed solar system would obviously vary with *G*. If age is given as being so many years, are orbital revolutions with the present value of *G* or with the varying values of *G* at different times intended? It might be argued that the time unit may be defined in terms of a process—as, say, molecular vibrations—which is presumably independent of *G* and for which the constants could be taken as not changing. However, we know of no absolute time measure in nature, and the choice of which constants are varying and which are not might well be an arbitrary one.

Milne suggested that there are two time scales, one for mechanical and a different one for electromagnetic phenomena, with a difference between the scales that depends on the epoch of the universe. The existence of two scales reduces essentially to a change with time in the relations between physical laws (or specifically, between physical constants). Thus, on Milne's view, the ratio between a pendulum frequency and frequency of electromagnetic radiation from a given atomic source changes with time.

It has sometimes been said that if physical constants do change, the problem of the age of the universe is impossible of solution. One estimates the age of the universe by extrapolating a process, observed at present, back to its beginning and thus estimating the time for the total process ; it is argued that if one cannot extrapolate natural law as discerned at present to all past periods one cannot justifiably make a total time estimation. The situation need not necessarily be taken as hopeless, however, even if physical constants are changing. It is conceivable that the rate of change could also be known, in terms of present-day units ; there would then be the possibility of finding a time equivalence between past physical processes and the processes used for defining present time units. An age might then be given in terms of established time units.

Our discussion of fundamental time variations in physical processes may seem to have gone somewhat beyond the content of present-day physical theory. The proposals for such variations are all highly speculative, and in general physicists and physical theory proceed on the assumption that physical laws and constants always are as we today find them to be. For reasons of simplicity such an assumption seems to be the proper one to make, barring compelling reasons to the contrary. None the less, changes in fundamental physical relations would be a factor of ambiguity in our time units, and the possibility of such changes cannot be ignored in considering the age of the universe.

Relativistic Time Changes. Aside from possible inherent changes in physical constants, there is yet another threat to the significance of our time units. The theory of relativity requires that the time rate of a physical process will vary with the velocity of the observer with respect to the process. Thus, as is well known, for the special case of unaccelerated motion, a process occurring in time t for a rest observer will presumably occur in a time $\sqrt{1 - v^2/c^2}\, t$ for an observer moving with a velocity v with respect to the process (c is the velocity of light). On the grounds of the relativity theory there would seem to be, then, as many 'ages of the universe' as there are observers with significantly different velocities between themselves.

In applications of relativity theory to problems of cosmology the possible plurality of time scales is, however, generally ruled out by an assumption of large-scale uniformity among the motions of the galaxies. The assumption has been explicitly stated by H. Weyl, and asserts in effect that local, random motions among a group of galaxies will be small compared with c; and that in their large-scale, high velocity motion, galaxies will 'stream out' uniformly, as from some initial space-time point, such that all have comparable motions with respect to the other galaxies of the universe. Each observer, then, will find nearby galaxies to be relatively motion-less with respect to himself, but may find high velocities for galaxies at far distances. A cosmic or universal time is then introduced because observers everywhere find the universe to be the same in its large-scale aspects. The available evidence has tended to support Weyl's postulate; for, as will be discussed in the next section, the observed galactic universe is one in which neighbouring galaxies move relatively slowly with respect to the earth, while far galaxies recede with high speeds that are proportional to their distances from the earth.

Expansion and Age. If we are to gain a statement of the age of the universe we must be able to observe some process that is associated with the life-span of the universe, and we must be able to estimate a time of beginning for that process. The recessive motions of the galaxies have seemed to many to provide such a process, and estimates made in recent years of a finite age for the universe have usually been largely based on the galactic motions.

Observations, carried to distances as great as the limit of the new 200 in. Hale telescope, have indicated a motion of the galaxies away from the earth. The velocity of recession of a given galaxy, v, varies linearly with its distance R from the earth, such that $v = kR$. The proportionality term, k, has been found to be the same for all observed galaxies, and is known as Hubble's constant. It is assumed that an observer in any other galaxy would find the same recessional motion as is observed from our galaxy; hence, the universe of galaxies is interpreted as expanding uniformly in all directions.

Hubble's constant does readily suggest a beginning of outward motion of the galaxies from an initial space-time point. With the constant written as $1/T$, the preceding equation becomes $R/v = T$. This equation may be taken to mean that the galaxies have velocities such that they have all reached their present distance R from a common point in the same time T. The observations of galactic distances and velocities lead to a value of about 2×10^9 years for T. We may argue, then, that some 2×10^9 years ago the universe, starting from a state of highly condensed matter, or perhaps starting with an event of creation of all matter, began to expand, and that therefore the age of the universe may be said to be about 2×10^9 years.

The values which have been obtained, by means of determinations of accumulated radio-active decay products, for the ages of the oldest rock strata of the earth must be considered in connection with the interpretation of T as the age of the universe. The rock ages are probably a good measure of the age of the earth, since cooling and hardening of the earth's surface, if the surface was originally in a molten state, would take place relatively rapidly. In any event, a suggested age which made the universe younger than the oldest rocks would clearly be unacceptable. The values found for these rock ages are in the range of 3 to 4×10^9 years. Considering that the creation of the earth would be expected to occur early in the expansion period, some have argued that the order-of-magnitude agreement between T and rock ages is impressive evidence for the interpretation of T as the age of the universe. More commonly, however, it has been held that T and the age of rocks should not disagree by as much as a factor of 2, and that the data on rock ages seriously weakens the arguments for interpreting T as the age of the universe.

Within the past year or two astronomers have been led to a reconsideration of their distance scales, with the tentative conclusion that all galactic distances R have been underestimated, perhaps by as much as a factor of 2. Any increase in R means a similar increase in T; so perhaps the contradiction between T and the rock ages will be removed. Close agreement between these values would be strong support for the view that the universe as we know it had its origin T years ago.

The Period of Expansion. Whatever might be the eventual conclusion about the agreement between T and the age of the earth, the interpretation of T as the total age of the universe is not likely to pass without objection. Suppose that we assume that physical laws and constants have not changed during the existence of the universe. Then our present time units are unambiguous throughout the expansion period, and to say that T is the age of the universe has a definite temporal significance. We now ask, however, what happened before the beginning of expansion. There seem to be two possible answers: one answer is that nothing happened, and that at the beginning of the T period there was an event in which all energy and space were created, with properties that would be described by the same physical laws then as now. The answer, resting as it does on an act of creation, hardly seems to be consonant with the continuity of process that we have come to expect in nature ; it is, indeed, an answer in the spirit of arbitrary assumption rather than of scientific inquiry.

The second possible answer is that there were other cosmic events previous to the beginning of the expansion period T. There might, for example, have been a preceding period of contraction of the universe, with expansion before that, and so on, as has been suggested in some relativistic cosmological models. If this answer is adopted, we retain a possibility of scientific inquiry into all stages of the universe. However, clearly T is not then the age of the universe, since there were events prior to T. Instead, we can only properly speak of T as being the age of the period of expansion.

If we do not make the assumption that physical laws have not changed, but instead take the point of view that with development of the entire universe there would have been changes in physical law, we lose the straightforward significance of T as an age of any kind. Only with a fairly complete theory of how the laws and constants of physics change, could we translate our present time units into units for physical processes throughout the period T.

We have, then, three possibilities for the significance of T with respect to the problem of the age of the universe : (i) physical laws have not changed, and T does give the time elapsed since creation of the universe ; (ii) physical laws have not changed, and T gives the length of a period of expansion of the galaxies ; (iii) physical laws are changing, and therefore the significance of T as a time measure is in doubt. For the reasons given, we shall reject (i). Also, we shall reject (iii) ; it is simpler to assume that physical laws are not changing than to do otherwise, and, as has been previously remarked, physical theory at present hardly more than suggests the possibility that there may be such changes. We are left then with (ii) as our preferred interpretation of T ; that is, we take T to be the age, not of the universe, but of a period of expansion of the observable universe. Since on this view the idea of an initial creation has been regarded as not justified by our present information, the universe must be regarded as having existed for an infinite time, if an age of any kind is to be assigned to it.

There is, however, still a fourth possibility which we must consider for the interpretation of T.

The Steady-State Universe. A theory has been developed by H. Bondi and T. Gold, and also by F. Hoyle, according to which the large-scale aspects of the universe are unchanging in time for all observers.

In this theory, expansion is an intrinsic property of the universe, but it is not required that all the galaxies expand from an initial, highly condensed state. Instead, it is assumed that matter is created more or less uniformly throughout space, at the rate of about one hydrogen atom (or equivalent mass) per litre of volume in every 10^9 years. The nebulae are formed by processes of accretion and condensation of the created matter, and are carried away from each other as a result of an inherent property of space, in accordance with Hubble's constant.

With matter being continually created, there is no need for an initial act of creation in the Bondi-Gold-Hoyle theory ; hence the descriptive name, ' the steady-state theory '. The galaxies, formed from the created matter, recede from the observer with velocities that increase with their distances, and eventually they reach the velocity of light. They then pass ' over the horizon ', and can no longer be observed. Conceptually, then, the universe is infinite in extension, but for each observer there is an observable universe which contains a finite amount of matter. It is a consequence of the theory that the average age of matter within the observable universe is $1/3\ T$. The age of any given galaxy may vary widely from $1/3\ T$; the entire universe obviously has an infinite age, since the creation and expansion are steady, continuous processes.

The authors of the steady-state theory have been able to cite evidence in support of their theory, and also have presented supporting philosophical arguments of considerable strength. The theory has implications with respect to such questions as the formation of galaxies, the variations among galaxies, and the density and kind of inter-galactic matter. Observations relevant to these questions may be expected to lead eventually to a decision for or against the steady-state theory. However, either the steady-state theory, or the interpretation of T as the period of expansion, with rejection of an act of creation at $T = 0$, give the same answer for the age of the universe : that is, an infinity of time.

Time in the Universe. If we take the age of the universe to be infinite we gain an answer to the question we have asked. The answer, however, will probably not be a highly satisfactory one ; for the concept of infinite time is difficult to appreciate intuitively, and violates acquired notions about things starting somewhere. Essentially, the dissatisfaction with ascribing an infinite time to the universe arises, we believe, because an infinite time is usually taken to apply over the existence of the universe in the same way that a finite time applies over a measurable interval. We will suggest that the universe, if ' infinite in time ', is properly not in time at all but rather is *time-less*, in a significant sense of that word.

There are two elements in our usual time measure. We have discussed the uniform, recurring cycles which can be used to constitute a clock. A second element is progressive change, in contrast with which clock cycles may be enumerated. If there were only cyclical processes in the universe, there would truly be no time in the customary sense, for there would be no way of distinguishing one cycle from any other. A feeling that actually one cycle would still be later or earlier than another is merely a residual notion from our every-day sense that time is everywhere flowing onwards.

In his life and surroundings man does of course find progressively changing processes in abundance. It is an easy step to the assumption that progressive change is an attribute of the universe generally, and hence, that time, with a unique sense of past and future, is inherent in the total universe. If, however, we believe that the age of the universe is infinite, because we do not find convincing evidence for a beginning point, we have then removed the universe from the class of processes that are characterised by progressive change. Clearly we have done so if we take the universe to be as described by the steady-state theory, for in that theory as presently developed the large-scale aspects of the universe do not change with time. If we accept the expansion of the universe from a highly condensed state, but deny that the universe began with that particular state, we ascribe to the universe fluctuations which have presumably persisted indefinitely. In either case, the large-scale universe is not presented as a process which shows a progressive change such that it is at any one consideration (or ' observation ') uniquely different from itself at any other consideration (or ' observation ').

We suggest, then, that the universe may be essentially *atemporal*. The physical time, with a well defined forward direction, which man finds in his life and surroundings, clearly shows that the universe contains possibilities for time-defining processes. But over-all there may be no such process in the universe, and hence, no meaningful way of ascribing a time or age to the universe.

The concept of the universe as atemporal may be illuminated by considering the time characteristics of the laws of nature. The laws of the fundamental entities of the physical world are, as is well known, reversible in time. Thus, Newton's equations of motion, or the Schrödinger wave equation, or Maxwell's electromagnetic equations, are equally valid for increasing or decreasing time values, as we apply the equations from some given instant. Or, put another way, if the end points of a given pattern of change are taken as initial points, the reverse may occur just as readily as did the original pattern. And yet for aggregates of matter there is a definite pattern of physical change which is irreversible in time, even though the elementary, individual components of an aggregate obey the reversible physical laws. The pattern for aggregates is as described by Boltzmann's *H*-theorem, or on a thermodynamic level, by the law of entropy increase for physical processes. For the elementary particles, then, a time sense, of going forward or backward in time, may be given only in terms of larger, truly temporal processes of which the particles are a part. We suggest that conversely these temporal processes may be elements in large-scale, cosmic processes for which no time order may be defined.

The difference between saying that the universe is atemporal and saying that its age is infinite is, I believe, a genuine one. The universe, if infinite in age, has a time order that is inherently a part of it. The universe is as if it had a beginning (and presumably will have an end), but these terminal points are beyond any enumerable number of time units. The atemporal universe has over-all structure, just as there is a structure among fundamental entities as indicated by the reversible physical laws, but there is no process inherent in the universe which is progressively changing and points toward a beginning in the past and an end in the future. Rather, it is only for limited sub-processes of the universe that time order, or past and future, may be defined. Any one process which progressively changed throughout the span of the universe by, for example, some kind of continual growth, would give a measure, finite or infinite, of the age of the universe. But if there is no process whatever which exhibits such a progressive change, there is no physical basis for applying the time concept to the entire universe.[1]

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[1] A referee of this essay has suggested the question, On the hypothesis of an atemporal universe would the number of years (or of any other physical measure of time) up to today be finite or not? The phrase ' up to today ' assumes of course that a progressively changing process, in terms of which an over-all cosmological time sense may be determined, is available. The hypothesis of atemporality, in contrast, rests on the notion that on the cosmological scale there is no aperiodic, progressively changing process which fixes the direction of time. Time is then only a ' local ' property, as for example in the domain of our observations of galactic

Conclusion. Our suggestion that the total universe be regarded as essentially atemporal might be objected to on the grounds that in the theories which indicate an infinite age for the universe there are possibilities for progressively changing processes that span the existence of the universe. Thus, in the steady-state theory matter is continuously produced. Is there not therefore a possibility that future developments will eventually give us a theory in which the mass of the total, conceivable universe gives a measure of the age of the universe? Likewise, in the view which takes the present expansion of the universe as being merely one phase in a universe of fluctuating expansions and contractions, may there not be more fundamental changes, as in physical laws themselves, which provide a progressively changing, physical basis for a time measure of the total universe? The answer to these questions must of course be in the affirmative. But, it is also obvious that in the discerning of a universal, progressively changing process, there is a strong likelihood of finding an extrapolation, backwards in time, to the beginning of the process. The probable alternative to an atemporal universe would seem, therefore, to be a finite universe rather than an infinite universe.

We have argued against the hypothesis of an act of creation of the universe T years ago. If further investigations should discredit rather than support the steady-state theory, the concept of a period of expansion of about T years duration will almost certainly continue to be seriously considered. But the proposal that the universe was truly created T years ago, in a great, unique event, is completely counter to scientific experience—experience which finds continuity of process in nature, with events proceeding in an orderly fashion from other events. It would seem that only strongly compelling evidence will make the act-of-creation hypothesis scientifically plausible. In all, the consideration of possible changes in physical laws presents a more attractive alternative to steady-state theory than do creation hypotheses. Such

expansion and evolution, and questions about the extent in time of the total universe may not properly be asked because there is no progressively changing process in terms of which an answer may, even in principle, be given. One might still wish to ask, *if there were* an observer who could count the number of years for which the atemporal universe has existed, would he not enumerate to an infinite number? However, the very co-existence with the universe of a progressively counting mechanism would mean that there existed a completely aperiodic process in terms of which a time sense and time duration could be defined for the universe. The universe would, then, not have the atemporal property which we have proposed for it.

considerations might eventually lead to a theory of the gradual development of the universe.

We must, however, draw our conclusions from fact and theory that are reasonably well established today. The lack of an obvious, progressively changing process which is a time measure of the entire age of the universe, and the atemporal quality of the equations for the elementary processes of the physical world, lead, it seems to me, to a final preference for the view that the universe is atemporal in its over-all aspect. An expression of preference is of course speculative —more significant today than any answer that can be given is the fact that the problem of the time characterisation of the universe seems to be coming, even if only ever so slightly, into the range of astronomical and physical studies.

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THE AGE OF THE UNIVERSE

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1 *Logical status of the concept*

We have first to specify the precise meaning of the concept in question in accordance with its customary usage and the requirement of logical self-consistency. There are different ways of interpreting the meaning of 'temporal origin of the Universe', namely:

(1) $T = 0$ designates a moment when space, time, and their material contents came into existence simultaneously: neither existed before.

(2) This moment coincides with the beginning of the present world state separating it from any previous cosmic history.

(3) Although the moment marks off an important epoch, the processes that occurred in the preceding phase have observable consequences at present, e.g. those of stellar evolution.

The third view is logically inconsistent, for if some processes can be traced back to $T < 0$ then it is possible, by regraduating the time scale, to attach the meaning T_0 to the earliest time-point deducible from those processes. The first two can be combined in the definition: Temporal origin is the zero-point of the time co-ordinate of the present development of the Universe which separates it completely from anything that might or might not have existed before. Adopting this definition of the point T_0 we define hereby the conception of the age of the Universe t as the value of the time co-ordinate counted from that point till the present point T_μ, in units of measurement τ. Thus by definition

$$t = \frac{T_\mu - T_0}{\tau} \qquad (1)$$

We proceed to analyse this concept regarding its applicability to the whole of the Universe.

If this started its evolution from one single point the conception of T_0 is unequivocal, but this is not the case if the Universe then possessed appreciable dimensions. Still more the difficulty is evident with respect to the moment T_μ. The assumption of simultaneity in different places of the Universe contradicts Special Relativity. Even if we renounce Special Relativity and somehow establish simultaneity for all the points in the world, we have still to assure a unique value of τ. According to General Relativity this is possible only if gravitational potentials and accelerations have always been exactly the same throughout. This is obviously not realised in view of variety of masses and motions of individual galaxies. Then the rate of time-flow will be different at various points and no time-unit τ could be applied everywhere. Attempts to re-introduce absolute time into the description of Nature under the name 'universal time' by the artificial device of 'clock synchronisation' (by light signals) fail due to lack of homogeneity in the Universe. There is no cosmic time, common to all points, and the concept of the age of the Universe as defined above contradicts both Special and General Relativity. If their essential principles are held true, that concept for the actual Universe is logically inconsistent.

2 *Observational evidence*

We cite below the data of the ages of some formations as given by the authorities indicated.

2.1 *Earth and Moon.* Ahrens[1] determines the ages of pegmatites from Manitoba as amounting up to 2·57 billion years (a billion being 10^9). Chamberlin[2] states that $\frac{3}{4}$ of zoological evolution took place before the Cambrian era, and sponges (Porifera) were found of billion age in Congo limestone by Dr Bain.[3]

Holmes[4] determines the age of the earth's crust as 3·35 billion years. Estimates of the earth's age in billions of years by various investigators are as follows: by Burling[5] under 5; Dehm[6] from geologic considerations 6 or more; Chackett[7] 3·5 at most (age of the atmosphere); Jeffreys[8] under 8; Koczy[9] under 5·3; Quiring[10] about 5·2; Unsöld[11] under 6·6.

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[1] L. Ahrens, *Nature*, 1947, **160,** 874

[2] R. Chamberlin, *The Atmospheres of the Earth and Planets*, Chicago, 1949, 258

[3] *Science News Letter*, 1951, 261

[4] A. Holmes, *Nature*, 1947, **159,** 127

[5] R. Burling, *Phys. Rev.*, 1951, **84,** 839

[6] R. Dehm, *Naturwissenschaften*, 1949, **36,** 166

[7] K. Chackett, *Phys. Rev.*, 1951, **81,** 1057

[8] H. Jeffreys, *The Earth*, Cambridge, 1924, 57, 78, 229

[9] F. Koczy, *Nature*, 1943, **151,** 24

[10] H. Quiring, *Beitr. Geophys.*, 1949, **61,** 125

[11] A. Unsöld, *Z. Astrophys.*, 1947, **24,** 278

For the age of the Moon Jeffreys[1] gives 4 billion years and Quiring[2] 3·1. This evidence indicates the existence of the earth for at least $4 \cdot 10^9$ years.

2.2. *Sun and Solar System.* For the sun's age Ledoux[3] gives 5 billion years and S. Meyer[4] 4·6. For the age of elements (equivalent to that of the solar system) Suess[5] gives under 6 and Burling[6] under 7. For the age of meteorites Paneth[7] gives various figures up to 6·8. Estimates of the age of the Solar system are: by Bok[8] and ter Haar[9] 6, and by Jeffreys[1] under 10. Thus this age is of the order of $(5 \text{ to } 6) \cdot 10^9$ years.

2.3 *Stars, clusters, galaxies.* The stellar ages of different spectral classes are not equal even in order of magnitude: whereas for the oldest stars Strömgren[10] gives 5 billion years, Unsöld[11] holds $1.3.10^7$ years as the maximal age of O7·5 stars. Galactic clusters of Pleiades-type are about 3 billion years according to Chandrasekhar[12]. For the age of the Galaxy Bok[8] gives 5; Bondi[13] 5 to 8; Chandrasekhar[14] from statistics of binaries about 3; Gondolatsch[15] from energy distribution of stars under 10; and Edgeworth[16] 9 billion years. Ages of extragalactic nebulae are different: for our neighbours Hoyle[17] gives 3 to 7, whereas the age of the clusters of galaxies according to Zwicky[18] exceeds 10 billion years.

2.4 *Universe as a whole.* The only evidence for the age of the Universe itself is obtained by extrapolation of recession velocities of galaxies into the past. Under linear extrapolation they yield $1 . 7.10^9$

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[1] H. Jeffreys, *The Earth*, Cambridge, 1924, 57, 78, 229

[2] H. Quiring, *Z. dtsch, geol. Ges.*, 1946, **98**, 172

[3] P. Ledoux, *Ann. d'Astrophys.*, 1948, **11**, 174

[4] S. Meyer, *S.B. Akad. Wiss. Wien Math.-nat. KL IIa*, 1937, **146**, 175

[5] H. Suess, *Experientia*, 1949, **5**, 278

[6] R. Burling, *Phys. Res.*, 1951, **84**, 839

[7] W. Arrol, R. Jacobi and F. Paneth, *Nature*, 1942, **149**, 235

[8] B. Bok, *Mon. Not. R. astr. Soc.*, 1946, **106**, 61

[9] D. ter Haar, *Rev. Mod. Phys.*, 1950, **22**, 119

[10] B. Strömgren, *Astr. J.*, 1952, **57**, 65

[11] A. Unsöld, *Z. Astrophys*, 1947, **24**, 278

[12] S. Chandrasekhar, *Ap. J.*, 1943, **98**, 54

[13] H. Bondi and T. Gold, *Mon. Not. R. astr. Soc.*, 1948, **108**, 252

[14] S Chandrasekhar, *Ap. J.*, 1944, **99**, 54

[15] F. Gondolatsch, *Z. Astrophys.*, 1947, **24**, 330

[16] K. Edgeworth, *Mon. Not. R. astr. Soc.*, 1948, **108**, 417

[17] F. Hoyle, *Nature*, 1949, **163**, 196

[18] F. Zwicky, *P.A.S.P.*, 1952, **67**, 247

years or, with correcting factor of 2 according to Struve,[1] $3 \cdot 4.10^9$ years $= t_{\text{lin.}}$. The reliability of such an extrapolation will be considered below.

2.5 *Summary of observational evidence.* Analysing the data cited above we arrive at the following general conclusions :

(A) The ages of the oldest formations are definitely much older than the 'age of the Universe' $t_{\text{lin.}}$ derived from the red-shifts.

(B) There is no reliable evidence for the existence of any bodies or formations much older than 10^{10} years or that order of magnitude.

(C) Ages of various bodies and formations do not converge to some common value ; on the contrary, considerable variety of figures is found out. Thus the concept of the age of the Universe, the same for the whole of it, has no observational foundation.

3 *Theoretical aspect of the age of the Universe*

We consider below the views about the age of the Universe that follow from the main existing theories, and we consider some of their observable conclusions.

3.1 *Static model.* Any static model of the Universe, e.g. Einstein's initial one, presupposes an infinite time for its existence. This contradicts Point (B) of the observational evidence and therefore such a model should be rejected, apart from its inability to account for the phenomenon of red-shift.

3.2 *Relativistic models of expanding Universe.* A recent discussion of the age in relativistic cosmology by McVittie[2] clearly elucidates the difficulties of the theory, e.g. the conclusion that pressure and density cannot both be positive during some periods of expansion, if linear and some other laws are assumed. He concludes : 'Hubble's constant is insufficient by itself to determine the age of the Universe.' Besides, the figure obtained, 3·4 billion years, is inconsistent with observational evidence (A), if the definition of the age given in (1) is accepted. However, relativistic cosmology developed many models. Among them there is one of an oscillating world. It is characterised by the properties : $R' > 0$; $R'' < 0$ in the expanding phase of oscillation (R = radius of space). This leads to an age still less than that derived from linear expansion. The same is true for the so-called

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[1] O. Struve, *Sky and Telescope*, 1953, **12,** 203

[2] G. McVittie, *Astr. J.*, 1953, **58,** 129

'Monotonous world of the first kind' (terminology due to Friedman[1]) in the first part of the expansion from $R = 0$ to the point of inflexion where $R'' = 0$.

Therefore, both these cases are ruled out as inconsistent with the ages observed. There remain for consideration 'Monotonous II model' of accelerated expansion and 'Monotonous I model' in its second part after the inflexion point. The time passed since the beginning obtained in Monotonous II model can be sufficiently long to accommodate the oldest formations observed. Lemaître[2] considers as an upper practical limit $17 \cdot 10^9$ years. However, in order to secure $t \gg 3 . 4.10^9$ years the rate of radius increase should be such that $R'' > \alpha^2 R$. Then the velocity-distance relation would acquire the form: $v = kr - lr^2$ . . . that can be compared with observation. Hubble's[3] analysis shows that rectilinear relation is obtained only if corrections to apparent magnitudes are assumed to be $\Delta m = 3\frac{d\lambda}{\lambda}$, which means a non-Doppler origin of red-shifts. If, to be consistent with the idea of expansion, Δm is assumed $= 4\frac{d\lambda}{\lambda}$, then the relation deviates from rectilinearity upwards, i.e. can be expressed by $v = kr + lr^2$ in direct contradiction to expectations (numerical values of k and l will be changed due to new scale but the character of the curve remains the same). The accelerated model, though capable of providing sufficient time $t > t_{\text{lin.}}$ fails to comply with observational data of red-shifts.

Assuming Monotonous I model in the point after inflexion, recourse can be made to the idea of staying some time in the equilibrium state, in order to lengthen the time available. But this hardly has a physical meaning. If, while passing through the equilibrium state, the expansion was temporarily 'frozen', then evolutionary processes should be frozen, too (i.e. produce no observable changes in the ages of stars). Otherwise, if all processes proceeded with full speed, it is not understandable why the expansion should be slowed down. Besides, both of the last two models are probably in trouble with the value of mean density of matter (see 5).

Thus, in spite of its flexibility and variety of forms, relativistic cosmology cannot achieve agreement with both observed ages and red-shifts. It is unable, therefore, to provide the basis for a theoretical estimate of the age of the Universe.

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[1] A. Friedman, *Z. Phys.*, 1922, **10**, 377

[2] G. Lemaître, *Rev. Mod. Phys.*, 1949, **21**, 357

[3] E. Hubble, *Ap. J.*, 1936, **84**, 517

3.3 *Kinematical expansion.* Milne's kinematical model provides for the development of the Universe in t-scale of time only $3 \cdot 4.10^9$ years and there is no possibility, without abandoning its basic ideas, of lengthening this time. Regraduation to the τ-scale of time gives no information about the actual age at all. This circumstance alone renders the model unacceptable.

There is another difficulty. This model, as well as the relativistic model of negative curvature of space, predicts radial increase of density with distance. If distance, however, is measured with optical means (by luminosity of objects), and there are no other ways at our disposal, then radial decrease should be observed.

Hubble's[1] analysis of nebular counts, again with magnitude correction $\Delta m = 4\frac{d\lambda}{\lambda}$, showed a marked increase of nebular density. To reconcile this with the theory, spatial curvature must be introduced; but this destroys the basis of it, because of the absence of dimensional constants.

3.4 *Steady-state model.* In this model the Hubble-constant α has no relation to the age of the Universe which is assumed to be infinite in the past and future. This infinity does not contradict (B), for all the formations older than some definite age, $15 \cdot 10^9$ years according to Hoyle[2] (after α-correction $25 \cdot 10^9$ years), conveniently disappear beyond the optical horizon. Yet their very existence gives rise to some worries. Growing older and more massive, due to new matter 'created' and capture of neighbouring galaxies, they tend to become infinitely massive assemblages. The presence of such powerful attractive centres is likely to check the expansion in their neighbourhood and start contraction, which once started will continue further, leading to the struggle between expanding and contracting regions. Whatever the ultimate result of such cosmic cataclysms may be, the homogeneous steady-state character of expansion will evidently be destroyed. Perhaps it is more reasonable not to worry about these unpleasant consequences as they occur outside the observable region. Out of sight, out of mind! As to observable evidence, unfortunately, this interesting theory makes no predictions about statistical distribution of the ages of galaxies. Purely qualitatively, a galaxy is the older, the farther away it is. Therefore, appearance of the older, more massive formations should exhibit some dependence on their distances. No such dependence has been found.

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[1] E. Hubble, *Ap. J.*, 1936, **84**, 517

[2] F. Hoyle, *Mon. Not. R. astr. Soc.*, 1948, **108**, 372

The largest Coma-, Virgo-, Pisces- clusters are within comparatively close distances of a few 10^7 light-years[1] and no larger clusters have been observed at any distances. Besides, there are indications that existing data are incompatible with fundamental postulates of the theory: non-linearity of the velocity-distance relation and the non-uniform density distribution mentioned above violate both homogeneity and steady-state requirements. (Correction $\Delta m = 4\frac{d\lambda}{\lambda}$ is often forgotten by cosmologists.)

3.5 *Summary of theoretical aspect.* Consideration of the theoretical aspect of the concept of the age, as it appears in the main models of the Universe, leads to the result that no theory is in complete accord with the data accumulated so far. Moreover, all of them have some inherent conceptual difficulties as, e.g. violation of the logical principle of continuity of existence (except the oscillating model), obscure reasons for the initial expansion rather than contraction (except the kinematical model), non-Maxwellian velocity distribution (in the kinematical one), light-velocities of material bodies contradicting Relativity (except the relativistic schemes where space itself expands). All of them contribute very little to the problem of the age of the Universe. Thus that conception has no theoretical foundations.

All three different lines of reasoning lead to the same result: assignment of a definite value for the age of the Universe, the same for the whole of it, has neither logical, nor observational, nor theoretical basis.

4 *The Structure of time*

4.1 *Meaning of the problem.* It happens sometimes that we formulate a problem in an improper way or seek the answer to a question that cannot be answered. One example of this was the question about the absolute speed of the earth through the aether. The answer was not obtained for the simple reason that such a thing as 'absolute speed' does not exist. Is it not possible that the problem under consideration is of the same kind? Perhaps the concept of 'Absolute age of the Universe' is also meaningless? Before answering this question let us consider an analogous problem involving spatial quantities.

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[1] E. Hubble and M. Humason, *Ap. J.*, 1931, **74**, 43

Suppose we are given a point P on a surface (restricting ourselves for simplicity to two dimensions). The problem consists in the following: does a point P_0 exist on its boundary, a spatial origin so-to-speak, and what is the distance $P - P_0$? To solve this problem we should undertake a preliminary investigation of the metrical properties and connectivity of the surface. After ascertaining that the Riemannian tensor is zero and the surface is a plane we can be sure that the problem is meaningful. In the case of a surface of positive curvature we cannot find P_0 anywhere and the concept of $P - P_0$ loses any sense. It cannot be either finite or infinite.

Now when we were confronted with a very similar problem involving temporal quantities T_0 (origin) and $T - T_0$ (age), we neglected the structure of time silently assuming it to be flat. Is this assumption necessarily true? Can we be sure that time is Euclidean any more than we can be sure of the Euclidean structure of space?

It is known that both geometries, hyperbolic and elliptic, are mathematically equivalent to the Euclidean one; which of them is actually realised in Nature is a matter for empirical decision.

A temporal counterpart for Euclidean space is Newtonian uniform time flowing from $-\infty$ to $+\infty$, time that appears in all cosmologies considered above. Besides, there exists a temporal counterpart for hyperbolic space: in de Sitter's cosmological model, real time is represented by a hyperbola. Still another kind of time is mathematically possible—time of positive curvature, analogous to Riemannian closed space, which we will call 'circular time'. Which one is realised in the Universe?

There is no *a priori* answer. Likewise, it is the matter for empirical decision by means of comparison of physical consequences with observation. One kind of possible time, de Sitter's, requiring an empty universe is already ruled out because of contradiction with experience.

Let us now consider logical justifications and observable consequences of the hypothesis of circular time.

4.2 *Time of positive curvature.* The conception of closed time is likely to give rise to objections that it has no sense, in so far as it means repetition of events in the Universe. Discussion of this objection we postpone till later (6); we will now consider philosophical principles justifying this conception.

(i) Introduction of positive curvature of time removes the metrical difference between space and time, which was unintelligible in view of the fusion of both by Relativity, and corresponds better to complete space-time reciprocity being 'a necessary part of the philosophical principle of relativity' according to Dingle.[1]

(ii) It is more in accord with Mach's principle: the material contents of the world determine its physical laws. Time is not sacrosanct and immune from being affected by the presence of matter in the Universe on the cosmic scale. In local condensations matter does affect time-properties (time-rate in stellar gravitational fields).

(iii) The assumption of time curvature abolishes its absoluteness, and this is more consistent with the spirit of Relativity.

(iv) The philosophical principle of continuity is preserved.

(v) The conception of finite time is in line with the principle of elimination of infinities from science. This can be credited with great merits in the past, namely, elimination of infinite velocities produced Special Relativity, elimination of infinite Euclidean space—General Relativity, elimination of infinite divisibility of energy—Quantum theory. It is to be expected that elimination of infinite time will lead to a better approximation to the structure of the Universe.

Besides adducing philosophical arguments favouring this concept we have to consider its physical consequences and compare them with experience.

(i) The effect of time curvature, usually insignificant, grows noticeable at large distances and consequently long intervals of time. It manifests itself in red-shifts of spectral lines as is shown in the Appendix (1), the form of relation being

$$\frac{v}{dc} = \frac{1}{\rho} = \alpha \qquad \ldots \qquad (2)$$

where the inverse value of the radius of time-curvature ρ is nothing else than the Hubble-constant α, from whose value we can compute the radius ρ as amounting to $3 \,.\, 4.10^9$ years. The above relation is a first approximation only, having to be replaced by the following one

$$\frac{v}{c} = tg\,\frac{d}{\rho} \qquad \ldots \qquad (3)$$

which constitutes one of the observable predictions.

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[1] H. Dingle, *Mon. Not. R. astr. Soc.*, 1934, **94**, 134

(ii) The time-cycle of the Universe has a finite value amounting to $T = 21 \cdot 10^9$ years, or $21 \cdot 10^9 \cdot \xi$ (see Appendix (2)) according to whether the time-curve is a circle or ellipse. Therefore no formations exist with an age exceeding T.

(iii) Ages of various bodies and formations can be different, for the time-points of their origin can coincide with any point of the time-curve.

(iv) The mean density of matter in the Universe is connected with its dimensions. Its minimal value is of the order 10^{-28} g./cm.^{3} but the actual density may by far exceed this as is shown in Appendix (3).

(v) Density distribution, as revealed by nebular counts, up to the magnitude 23^m, should reveal an effect of positive curvature—radial increase, which can be either isotropic or anisotropic (in the case of ellipticity). These physical consequences do not contradict the experimental data available.

4.3 *Concept of temporal origin and age from new viewpoint.* The preceding discussion was necessary for formulating the answer to the problem presented. Indeed when we deal with the age of the Universe, the properties of time should first be investigated, for the answer depends on them. From the viewpoint of this hypothesis there is no point T_0 in the circle of finite time that might be called the temporal origin of the whole Universe. Each of its points can serve as an origin to individual formations and these individual origins are distributed along the whole circle. The age of some formation is the phase of its evolution along the curved time. Therefore, there is and can be no such a thing as the ' Age of the Universe ' as a whole. Instead one can perhaps attach this name to the length of time-circle without implying that it refers to all the formations existing in the world. It is simply the maximal age possible in the Universe. Then Hubble's ' constant ' still has some relation to the age in this new sense representing the magnitude of time-curvature, either constant (in case of circular time) or instantaneous in a given point (elliptic time). The size and subject of this article do not allow a detailed consideration of the physical implications of finite time.

However, whether what occurs is a process of restoration of irradiated matter back from radiation as was suggested by McMillan,[1] or from fluctuations of ' Nullpunktenergie ' according to Nernst,[2] or whether the circle of stellar evolution closes up (and begins) with the phenomenon of Supernova-explosion from which a star (or rather nebula, first) emerges as a phoenix out of its own ashes to a new cycle of life, or whether other as yet unsuspected processes exist, does not matter. If time actually possesses the property of being curved, then some physical process must exist anyhow, for time is not an independent entity standing aloof but simply one aspect among others of the properties of matter. In this sense conception of closed time is just a synonym for circle-running physical processes including changes of entropy, whose increase was often associated with Eddington's ' arrow of time '. If this ' arrow ' proves to be curved and pointing back on itself, then increases of entropy must alternate with decreases, the total in the Universe remaining constant. Relativistic thermodynamics, as was shown by Tolman,[1] admits of such a possibility in a periodic universe.[2]

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[1] W. McMillan, *Ap. J.*, 1918, **48,** 35

[2] W. Nernst, *Z. Phys.*, 1935, **97,** 511

5 *Possibility of empirical decision*

Thus the structure of time is of decisive importance for the problem in question. Can we assume this structure at will or on aesthetic grounds?[3] Can we be content with the possibility of bringing the metric to a customary form by a proper transformation of co-ordinates? In this connection we should like to quote de Sitter [4] whose viewpoint we join completely : ' Our space and time are not mathematical concepts, which can be chosen at will, but are determined by the physical status of matter and energy. Thus, for example, it is not a matter of convention whether space is curved or not, but this must be found out from observations.' The same is true regarding curvature of time.

We have to base our decisions on observational evidence, though perhaps it is inadequate at present ; still growing rapidly and capable of producing crucial arguments in favour of one or another theory.

Let us review the kind of arguments required to settle the question. The most important data wanted are as follows :

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[1] R. Tolman, *Phys. Rev.*, 1931, **38**, 797, 1758

[2] The theory described above refers to the Macrocosm only and implies determinism of macrocosmic events. The question about microcosmic phenomena, whether quantum indeterminacy will prove to be final or be reduced to deterministic effects of ' some hidden variables ', as suggested, e.g. by D. Bohm in his causal interpretation of the quantum theory (*Phys. Rev.*, 1952, **85**, 166 ; 1953, **89**, 458) must be left open pending future investigations in that field.

[3] M. Johnson, *Amer. Scient.*, 1951, **39**, 412

[4] W. de Sitter, *B.A.N.*, 1933-6, **7**, 205

(i) *Future course of the red-shift—distance relation.* The deviation of this relation downwards would favour a relativistic, accelerated model. The opposite deviation, favouring the tangential dependence proposed (4.2), would eliminate all relativistic models in view of the short time-scale. Deviations to either side are incompatible with the steady-state model.

(ii) *Mean value of matter-density in the Universe.* Since the oscillating and Monotonous I models (in the lower part) are excluded (see 3.2), in the remaining relativistic models the present mean density of matter should be considerably less than the 'cosmological density' corresponding to the Einsteinian equilibrium state. Its value is of the order 10^{-27} according to Lemaître[1] or $3 \cdot 10^{-28}$ g./cm.^{3} after scale revision. It would therefore be a great surprise to relativistic cosmologists if in spite of an incessant 'flight of galaxies' the latter would happen to be in the same places, i.e. the present density would turn out to be equal (or higher) to the initial density, as recent estimations by Zwicky[2] seem to indicate, of the order 10^{-26} g./cm.^{3} (after scale revision $\sim 10^{-27}$).

The situation was apparently anticipated by Lewis Carroll, for it resembles one of Alice's adventures: '"Faster! Faster!" cried the Queen. And they went so fast that they seemed to skim through the air. The most curious part of the thing was, that however fast they went, they never seemed to pass anything.'

In the Wonderland of Expanding Universe, however, one does not seem to be aware (unlike Alice) of passing nothing.

Confirmation of the value $= 10^{-27}$ g./cm.^{3} will be fatal to any kind of expanding models.

(iii) *Further course of nebular density distribution.* Increase of density outwards and eventual anisotropy will be incompatible with many models. As additional means we may mention Zwicky's[3] criteria based on the analysis of 'dimensionless morphology' of galaxies.

The data listed above will enable one to discriminate between various possibilities and choose one that corresponds best to the actual structure of the Universe and its time constituent, a necessary prerequisite for the solution of the problem of its age.

For the reader's convenience the data discussed above plus some not discussed for the lack of space are compiled in the following table.

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[1] G. Lemaître, *Rev. Med. Phys.*, 1949, **21**, 357

[2] F. Zwicky, *P.A.S.P.*, 1952, **64**, 242

[3] F. Zwicky, *P.A.S.P.*, 1951, **63**, 17

Comparative Table of Various Models

Model	*Static Universe*	*Expanding Universe*			*Repeating Universe*		*Remarks*
Property		*Relativity*	*Kinematical*	*Steady state*	*Circul. time*	*Ellipt. time*	
Curvature of space	Const. +	Const. (±0)	Const. (−)	0	Const. +	Variable +	
Gener. Outlook	Homog.	Homog.	Homog.	Cluster.	Homog.	Clustering	
Mean density	?	$^{\star}< 3\cdot 10^{-28}$	$< 3\cdot 10^{-28}$	$1.5\cdot 10^{28}$	$\sim 10^{-28}$	$\geqslant 10^{-28}$	★ Cosmol. dens.
Nebular counts	Increase	Various	Decrease	Uniform	Increase	Increase	Outwards
Isotropy of Density	Isotr.	Isotr.	Isotr.	Isotr.	Isotr.	Non-isotr.	
Meaning of red-shifts	Cause unknown	Doppler-effect of true velocities			Distance-effect of time-curvature		
Vel.-dist. relation	?	$v = kr \pm lr^2$	$v = kr + lr^2$	$v = kr$	$v = kr + lr^2$	$v = kr + lr^2$	2 terms shown
Meaning of Hubble constant α	?	R/R	$1/t$	$C/R^{\star}$	$1/\rho$	$1/\rho$ inst.	*t*-pres. epoch $R^{\star}$-observable
Age of Universe	∞	$\overset{>}{\underset{<}{=}} 3.4\cdot 10^{9}$	$3.4\cdot 10^{9}$	$(25\cdot 10^{9})$	$(21\cdot 10^{9})$	$(\overset{>}{\underset{<}{-}} 21\cdot 10^{9})$	Oldest age observable

(Data and relations pertaining to Expanding Universe models are taken from various articles of their originators : Lemaître, Milne, Bondi-Gold, Hoyle. Numerical values are corrected for a new α-value.)

6 *Conclusions*

We have still to answer an objection that the Universe with a closed time would be meaningless, for the repetition of cosmic history makes no sense. Consider first what is the meaning of cosmical developments in other models. Every star ends its career after the exhaustion of subatomic and gravitational resources and every galaxy will represent a cemetery of lifeless bodies. And the whole Universe, unless new matter emerges mysteriously out of nothing, is going to a 'heat-death in which the total energy of the universe is uniformly distributed, and all the substance is at the same temperature'.[1] It is difficult to see why such a perspective should appear more meaningful than repeating rejuvenations of old formations to new cycles of life. Is there any sense in these repetitions? Such a question can be answered just as little as the question about the sense and meaning of the existence of the Universe at all. One has to admit quite frankly: *ignoramus, ignorabimus.*

The human mind cannot penetrate into eternal mysteries of nature, nor can it understand the means and purposes of the Great Architect of the Universe. One can only guess that the sense and meaning of nature is not confined to its material aspect. It is more probable that the true essence of Cosmos is on a higher level, and any scientific picture of the world, restricted necessarily to its physical contents, does not describe the Whole.

APPENDIX

1 *Red-shift*

One system moving with respect to another with velocity V gives rise to the change of frequencies expressed by formula:

$$\frac{\nu'}{\nu} = \frac{1 - v/c}{\sqrt{1 - v^2/c^2}} \quad . \quad . \quad . \quad . \quad (1)$$

Transition from one Galilean 4-dimensional system to another is obtained by rotation of the system through angle ϕ connected with relative velocity V as follows:

$$e^{-i\phi} = \frac{1 - v/c}{\sqrt{1 - v^2/c^2}} \quad . \quad . \quad . \quad . \quad (2)$$

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[1] J. Jeans, *The Mysterious Universe*, Cambridge, 1947, 15

Hence

$$e^{-i\phi} = \frac{\nu'}{\nu} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

i.e. the motion of a system is equivalent, as far as the production of frequency change is concerned, to the rotation of a 4-dimensional system through an angle ϕ. Now consider two co-ordinate systems: one with its origin at the point O (observer on the earth) and the other with its origin at the point N (distant nebula). In view of the curvature of both space and time their co-ordinate systems are turned to one other through the angle $\phi = \frac{d}{\rho}$, where d is the distance ON in time, and ρ is the radius of time curvature. The effect of this turn is to produce a change of frequencies equivalent to a relative velocity V, i.e.

$$e^{-i\phi} = e^{-i\frac{d}{\rho}} = \frac{\nu'}{\nu} = \frac{1 - v/c}{\sqrt{1 - v^2/c^2}} \quad . \quad . \quad . \quad (4)$$

A simple transformation brings this to the form:

$$i tg \frac{d}{\rho} = \frac{v}{c} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

(where i means just perpendicularity of space-dimension to ρ-dimension).

At small distances, when tangents can be replaced by angles themselves, (5) reduces to:

$$\frac{d}{\rho} = \frac{v}{c} \quad \text{or} \quad \frac{v}{dc} = \frac{1}{\rho} = \alpha \quad . \quad . \quad . \quad . \quad (6)$$

which expresses apparent velocity—distance relation.

2 *Length of time-cycle*

If the curve of closed time is a circle, then its circumference is simply $T_c = 2\pi\rho = 2\pi.3 \,.\, 4.10^9 = 21.10^9$ years. If, however, the curve is an ellipse, we have to find an expression for the length of its boundary from the following considerations. The connection between the radius of curvature ρ at any point of an ellipse and the major semi-axis a is given by formula:

$$\rho = \frac{a^2(1 - \epsilon^2 \cos^2 \alpha)^{\frac{3}{2}}}{b} = \frac{a(1 - \epsilon^2 \cos^2 \alpha)^{\frac{3}{2}}}{(1 - \epsilon^2)^{\frac{1}{2}}} \quad . \quad . \quad (7)$$

The connection between the boundary of the ellipse and a is as follows:

$$T_e = 4a\int_0^{\pi/2} \sqrt{1 - \epsilon^2 \sin^2 \alpha} \,.\, d\alpha = 2\pi a\left[1 - \tfrac{1}{4}\epsilon^2 - \tfrac{3}{64}\epsilon^4 \;.\;.\;.\right] . \quad (8)$$

Combining (7) and (8) we obtain :

$$T_e = 2\pi\rho\left[\frac{(1-\epsilon^2)^{\frac{1}{2}}(1-\frac{1}{4}\epsilon^2-\frac{3}{64}\epsilon^4\ .\ .\ .)}{(1-\epsilon^2\cos^2\alpha)^{\frac{3}{2}}}\right] = 2\pi\rho\xi \quad . \quad (9)$$

T_e is maximal when $\alpha = 0$; then $\xi = (1-\frac{1}{4}\epsilon^2-\frac{3}{64}\epsilon^4\ .\ .\ .)/(1-\epsilon^2) > 1$ and $T_e > T_c$.

T_e is minimal when $\alpha = 90°$; then $\xi = (1-\epsilon^2)^{\frac{1}{2}}(1-\frac{1}{4}\epsilon^2-\frac{3}{64}\epsilon^4\ .\ .\ .) < 1$ and $T_e < T_c$.

3 *Mean density of matter*

The field equations $R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}\ R + 2g_{\mu\nu} = -\ KT_{\mu\nu}$ have the following solutions for the cases of circular and elliptic time respectively

$$\sigma_c = \frac{1}{4\pi G\rho^2} \quad \text{and} \quad \sigma_e = \frac{1}{4\pi GP^2} \ (P = \text{parameter of ellipse}) \ . \quad (10)$$

For the case of circular time, if $\rho = 3\ .\ 4.10^9$ years, $\sigma_c \cong 10^{-28}$ g./cm.^{3}

The relation between ρ and P, in view of (7) and $P = a(1-\epsilon^2)$ is as follows :

$$P = \rho\,\frac{(1-\epsilon^2)^{\frac{3}{2}}}{(1-\epsilon^2\cos^2\alpha)^{\frac{3}{2}}} \quad . \quad . \quad . \quad . \quad (11)$$

When $\alpha = 0$, $P = \rho$; at $\alpha = 90°$ the relation is as follows :

$$P = \rho(1-\epsilon^2)^{\frac{3}{2}} \quad . \quad . \quad . \quad . \quad (12)$$

Considering formulae (10), (11), (12) we see that density σ_e in the world with elliptic time can never be less than σ_c, but in the most likely cases it will exceed σ_c and amount in the extreme case to

$$\frac{\sigma_c}{(1-\epsilon^2)^3} \gg \sigma_c.$$

Mannheim,
Kepler Strasse, 21.

GALILEO'S METHODOLOGICAL PROBLEMS

ENGLISH speaking scientists owe a great debt of gratitude to the Americans for their valuable translations of the classics in the history of planetary systems. This publication [1] maintains the fine tradition. Is it too much to request that they should consummate their good work by translating Kepler's *Commentary on the Motion on Mars*, which solved the age-old problems that defeated Ptolemy, Copernicus, and Tycho ?

Galileo's main purpose was to attack the orthodox Aristotelian science and to confirm the Copernican system by more reasonable interpretations of the observational data, some of which he had himself supplied. As this work has been so inaccessible it is desirable to describe briefly its subject matter. In the first dialogue the Aristotelian theory that the celestial bodies are unalterable and totally different from the earth is demolished by referring to new stars, earth-shine, and his own telescopic observations of sunspots and the moon. Early in the second dialogue Galileo presents seven arguments to support the view that diurnal motion belongs to the earth but not to the rest of the universe. There follows a brilliant discussion of whether local motions would be affected by the rotation of the earth, and the battle rages over thought-experiments on the motion of cannon balls, arrows, and falling bodies on land and on board a moving ship. The third dialogue contains the most important discoveries as far as planetary systems are concerned (pp. 318-345). These are Galileo's telescopic observations of the variation in the apparent diameters of the planets and the gibbous phase of Venus. The former gave the death-blow to the concentric spheres system of Aristotle, and confirmed the Copernican *and* Ptolemaic systems when analysed according to Galileo's theory of irradiation. The latter greatly weakened the Ptolemaic system. The moral of humility and tolerance applies to the last dialogue in which Galileo sharply rejects the lunar explanation of the tides, and elaborates his favourite theory that the tides are caused by, and therefore demonstrate, the motion of the earth. The modern authoritarians attacked in Einstein's Foreword should note that not only were Galileo's inquisitors fallible, but even the original genius himself was not infallible. His tidal theory landed him in sterile complications and even logical and empirical contradictions (see E. J. Aiton, *Annals of Science*, 1954, **10**, 44).

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[1] *Dialogue concerning the Two Chief World Systems.* Galileo Galilei, trans. by Stillman Drake, foreword by Albert Einstein. Cambridge University Press, 1954, pp. xxviii + 496, 75s.

It is sometimes suggested that Galileo's eminence arose because he discovered scientific method, but the most novel feature of his science was that it was frequently right. He was, however, concerned with methodological problems ; and the two main ones he had to face in his efforts to prove that the earth moves were, firstly, the nature of empirical confirmation and, secondly, the rôle of simplicity as a symptom of the ' truth ' of scientific theories (pp. 117, 327).

In connection with the first of these, he warmly praised Aristarchus and Copernicus for preferring the heliocentric system because of its kinematic simplicity, in spite of the contrary evidence of their sense experience (pp. 328, 339, 341 sqq.). Thus Professor Einstein in his Foreword justly criticises the argument that Galileo was a strong exponent of empiricism against rationalism. None the less, he agreed with Aristotle that observation is of primary importance (p. 55). From these facts it seems that Galileo failed to realise that the empirical test is never absolutely against a theory, but only against the whole corpus of supposed knowledge of which the theory is a part.

Now let us consider the second or supra-empirical problem. Having failed to find any certain empirical proof that the earth moves, Galileo fell back on the Principle of Simplicity. He applies this Principle many times (e.g. pp. 60, 123, 396, 448), and like Aristotle, Ptolemy, and Copernicus, he believed that a true theory must reflect the simplicity of ' nature '. In stating that Aristarchus and Copernicus had committed a ' rape upon their senses ', Galileo is conceding that initially it was simpler to say with Aristotle and Ptolemy that the earth does not move. However, he realised that, as new observations had become available, the Aristotelian system had become involved in ever greater difficulties and *ad hoc* complications in attempting to account for them (pp. 57, 341). Throughout the book all these extravagances were mercilessly and roguishly exposed, and the Aristotelian system was obviously shattered beyond hope of recovery by his telescopic observations. These enabled him to localise directly the main source of error, contradiction, and extravagance in the assumption that the distance of the sun, moon, or any planet from the earth does not vary (p. 321).

It is very appropriate that the Foreword to this translation has been written by Professor Einstein, for Galileo struggles hard, especially during the second dialogue, with the problem of the relativity of motion. Galileo's achievements have been belittled on the ground that, since we observe only a relative motion of the sun and earth, there is no difference in meaning between the theories, (*a*) that the earth moves round the sun, and (*b*) that the sun moves round the earth. Galileo passionately believed that the first theory is not only meaningful and different, but also ' true ' (see pp. 130, 281, 356). He anticipated that the first theory would turn out to be more practical scientifically, in the sense that a system of deductions based on it would remain simpler and would have greater empirical accuracy and lead to more accurate predictions than the second theory whose consequences would include a whole system of errors (pp. 57, 322, 341).

The relativists are of course correct in arguing that a mathematical astronomer can always make the earth the centre of co-ordinates for the analysis of the planetary observations. In fact, Kepler showed that *some* geostatic systems, the Ptolemaic and Tychonian, could be used almost as conveniently as the heliostatic system, always provided that a component, equivalent to the earth-sun orbit, be separated from the motion of each planet relative to the earth and proportional to its distance from the earth. That this mode of analysis remained possible, necessary, and fruitful, is one of the most significant facts for the student of the logic of science. *No* planetary system is recorded which did not separate out the earth-sun component at all. (The 'Law' of Inertia has also been interpreted by G. J. Whitrow, primarily as a method of analysis.)

The study of the Aristotelian and Babylonian systems is of primary importance, because they were unique in that they only slightly made the separation. Since the complete collapse of the former system early in the seventeenth century, astronomers have had no alternative but to separate out more and more exactly the earth-sun component, and this is equivalent to using a heliocentric system. It is taking a pride in necessity to call such a forced choice a 'pure convention', to use Professor Einstein's phrase. Still less should it be called a meaningless choice. Originally there was no reason for preferring the left hand side of the road rather than the right for motorists. That selection was a 'pure convention'.

The idea of separating the earth-sun component had first to occur to someone, and Apollonius, Hipparchus, Ptolemy, and others had to discover how to develop this idea to account for the observations accurately. Even when the concentric spheres theory and the heliocentric theory were equal rivals a choice was not made by pure convention. Both theories were developed until the former could be rejected rationally and scientifically on grounds of complexity. Still less was there a selection by convention after Galileo falsified the former theory by observation. The empirical accuracy, economy, predictive value, and discovery value of the heliocentric theory continued to be so excellent that astronomers knew their past confidence had been well-placed, and this justified continually increasing their confidence in it for future predictions. Despite the fact that all observations are made from the earth and not from the sun, the directions and distances of the planets from the earth are predicted in the *Nautical Almanac* on the basis of their positions relative to the sun, calculated in the *Astronomical Papers of the American Ephemeris*. No selection by pure convention between the heliocentric and Aristotelian system was ever called for, decided, or enforced by any scientific organisation. Some theologians attempted to enforce on Galileo a selection based on extra-scientific reasons, but the history of the repercussions of their efforts should dissuade modern theologians and politicians from similar interventions.

Galileo would never have agreed that the heliocentric theory was meaningless or a mere convention (p. 53). The foregoing account of the history of planetary systems fully vindicates his conviction that the superiority of the heliocentric system would become increasingly obvious, and re-endorses the greatness of his achievement in completing the Copernican revolution. Thus it is clear that, despite modern detractors, Galileo's book will always remain a classic of science.

Mr Stillman Drake's notes are very helpful, but it is incorrectly stated (p. 53 n.) that Copernicus did not use eccentric constructions. Galileo's main purpose was to give a popular survey of his discoveries and arguments in physical science. Thus it provides an excellent introduction to the history of the subject in the first half of the seventeenth century. Moreover, this translation is much clearer and more readable than the translation of Salusbury.

George Thomson

METHODOLOGICAL ASPECTS OF PHYSICS AND GEOMETRY[1]

These books are the first and third volumes, respectively, of a new series edited by M. Destouches. The series is designed to provide a complete and authoritative survey of the whole of theoretical physics which may serve as support for an advanced University course. *Quâ* textbooks, these two volumes fall outside the scope of a review in this *Journal*; but both contain also some discussion of the methods and concepts of physics, and it is for this reason that they are of import here.

M. de Broglie's book reproduces the course taught by him at the École Normale since 1934. It is a lucid exposition ranging from a summary of Maxwell's theory and of relativity to Dirac's equations. For the philosopher of science the interest lies in the way in which the author introduces and develops wave mechanics; the emphasis is always on the fundamental ideas, and there are many remarks about the difficulties and limitations of present-day theories.

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[1] *Méthodologie : Notions géometriques*, Jean-Louis Destouches (Gauthier-Villars, Paris, 1953. Pp. xi + 228. 3,000 fr.)

Éléments de théorie des quanta et de mécanique ondulatoire, Louis de Broglie. (Gauthier-Villars, Paris, 1953. Pp. viii + 302. 3,000 fr.)

M. Destouches begins his volume with a long chapter devoted to the methodology of physics. His main question is, What is a modern theory? The distinction between mathematical and theoretical physics is drawn. But there is still another, and new, branch which plays the same part for theoretical physics as logic does for mathematics. In analogy to meta-mathematics this should be called ' meta-physics ' ; but the term being in use already in a different sense, it is proposed here to call the new study ' physical logic ' (physico-logique).

The conception of a physical theory as a deductive system is then described in detail, e.g. the independence of primitive terms, their coherence, and the consistency of the system (in the Gödel sense). Tarski's method is discussed, i.e. that one can show the consistency of a theory Th by means of a model theory Th_0 to which, *in part* Th can be made to correspond. For example, the consistency of thermodynamics can be shown, according to the author, by applying it to the theory of total differentials which constitutes a part of classical analysis.

But it is impossible to accept a universal and immutable system of logic: for each particular theory a different logic has to be adopted. The *idealistic* definition of terms—subject only to the condition of being non-contradictory —gives rise to a different theory than does the *constructible* definition, that is, a definition which follows certain rules in the manner of Borel and Brouwer. A *descriptive* definition is given by specifying an operation, e.g. ' x is such so that px is true '. This can be accepted only if the proposition ' $\exists x . px$ ' does not produce a contradiction, and so it depends on the rules chosen for the system. Finally, the theory is said to be formalised when the primitive terms are replaced by symbols ; in this way well-formed formulae are obtained, and the deductive theory becomes a calculus.

A physical theory is, however, more than a deductive system ; its primitive terms possess a physical meaning, that is, they are related to experiment. The logical analysis of a theory must be supplemented by an *inductive synthesis*. How do we obtain these physical concepts? According to M. Destouches, ' Les concepts seront issus du concret par schématisation et abstraction '. This precedes the axiomatisation ; and all progress comes from axiomatising an incomplete theory. For example, the de Broglie waves are explained only by the principles of interference and of spectral decomposition, for these represent basic axioms for wave mechanics. Therefore, *partial* deductive theories are so important since they suggest limitations and, with them, new axioms needed to obtain a more complete theory. Neither Cartesian intuition nor appeal to facts suffice, however, to justify the fundamental concepts. The inductive synthesis is wider than, and really different from, what is usually taken as induction. It explains, by a great number of procedures, all the factors (including historical ones) which lead to a certain concept of postulate.

The hypothetical-deductive method is said here to be insufficient since we must sometimes assert certain statements and not merely entertain them as hypotheses, when we construct theories.

Axiomatisation therefore represents the boundary between the inductive and the deductive part of a theory. Over and above the formal conditions a theory has to satisfy the condition of *adequacy* which ensures the relation to experiment. A theory is adequate if it enables us to predict the results of future measurements. Its domain of adequacy is given by the *ensemble* of all possible experimental results and can therefore not be determined by deductive reasoning within the theory. Newtonian mechanics, for example, ceases to be adequate for particles of high speed or for microscopic particles ; but the need for modifying it arises from experiment, and not from internal limits of validity.

But how do we construct a theory so as to remain within the domain of adequacy ? There are two *positive* rules. A theory must not contain elements which cannot be measured by the kind of apparatus suitable for the theory in question. And no hypotheses may be introduced implying possible measurements which, in fact, cannot be made. These rules restrict, for example, cosmological theory if it is not to be an idle speculation.

Another method of constructing theories is that of ' adjoining abstract elements '. Abstract elements are joined to elements having a direct physical meaning, and so the theory may be completed. Or, we may make an *ensemble* of physical elements correspond to one of abstract elements ; e.g. in classical mechanics, motion may be represented by the path of a phase-point in configuration space. In wave mechanics, the ψ-function is an abstract element which we need as intermediary between observables and calculus.

How are theories changed and improved ? If a theory is either completely inadequate or ill-fitting (gauchement adéquate), no directives can be given for obtaining a better theory : it is a matter of inventiveness. But a *partially* adequate theory can be improved (1) by a critical examination of its domain of adequacy, (2) by determining the essential characters which we want to preserve in any new theory, and (3) by making appeal to a new, simple, idea—which is what is usually needed.

If the essential characters are indispensable but contradictory, then we must form a *complementary* system. The contradiction is eliminated by a logic of complementarity, and so we can construct theories *antithetical* to the original theory Th_0. A new *synthetical* theory Th_1 then unifies the partial, contradictory, theories.

A new, partial, theory Th_2 is obtained by rejecting some of the characters of the partially inadequate theory Th_0 ; but a positive contribution is needed, too, i.e. a new idea, in order to fix the elements which remained undetermined in Th_2. If the idea is not adequate, however, we have only obtained another, partial, theory Th_3; and so on. Finally, we may arrive at a *saturated* theory to which no postulate can be added without introducing a contradiction; this is the desired, new, theory Th. Starting from de Broglie's thesis, for instance, we add the idea that waves are associated with all material particles; the theory Th_2 is the first formulation of wave mechanics; the theories Th_3, Th_4, etc. are the improved versions as given by later authors, e.g. containing the principle of interference, the quantification of Schrödinger, the wave in configuration space of von Neumann, etc. We so arrive at the present-day, and in the author's opinion definitive, form of wave mechanics.

The changes of a theory are a normal episode in the development of physics: it is a *dialectic* process, from an initial theory to the antithetical one, and then unifying them in a synthetical theory. An axiomatised theory is therefore only an instantaneous stage in the succession of physical theories.

The theories of classical physics are *objectivist*; every value is objectively fixed, independent of the procedures of measurement; and the theories obey the rules of classical logic. Quantum physics embodies the principle of *subjectivity*. A microphysical system is known only by a measurement carried out by an observer with the help of a macroscopic apparatus. Therefore, the author argues, the actions of the observer cannot be eliminated from the description; moreover, there exist pairs of quantities that cannot be measured simultaneously. From this follow the indeterminism and complementarity of quantum theories, and we need a non-classical logic of ' subjectivité '.

This summary account of M. Destouches' methodology shows that there exists some measure of agreement among physicists about what constitutes a theory. Mathematical logic is now widely accepted as suitable for providing the formal treatment of physical theories. But there are wide divergencies when it comes to describe the non-formal aspect of physics.

It is here where the philosophical background of the methodologist becomes noticeable, that is, his particular brand of epistemology. Epistemologies, however, are neither necessary nor useful in science; with their implicit commitments they introduce irrelevant problems and, in the end, only lead to confusion. For example, the distinctions of subjective/objective and of abstract/concrete are practically meaningless, and so are many of the so-called inductive arguments. All such ontological assumptions can be discarded by taking the concept of *meaning* as basic and by using modern logic, in the wider sense of semantics, as a tool for the analysis of physical theory.

It was Einstein who first distinguished between a mathematical and a physical theory. A theory consists of a (logical and mathematical) calculus and of an interpretation in terms of experience; and while syntactic rules specify the calculus, the semantic rules refer to possible experiments. In an axiomatised theory the mathematical formulae, at least the main ones, are separated from the physical principles interpreting them, e.g. as in Carathéodory's thermodynamics. The formalisation of a theory would consist in separating completely the calculus from the interpretation, and the theory itself from the meta-theory, that is, from the statements needed to explain the theory. A theory is not formalised by merely translating verbal statements into an array of symbols; this view—suggested by M. Destouches—is not shared by contemporary logicians.

It is, however, true that induction, as philosophers have understood it, plays little rôle in science. Most practising physicists agree that the main task lies in constructing theories and in improving them. Operationalist ideology is not very helpful here. Though the measuring process and the apparatus have to be considered, theories are not built by dialectic—whatever this obscure term may mean. A theory of measurement is always interposed between the experiment and the theoretical statements for which it is a test. There is no difficulty in classical physics: both the phenomena and the measuring apparatus are on the macroscopic scale, and the theory allows us to neglect the interactions introduced by the measuring process. In quantum physics, there is a law limiting these interactions, i.e. the uncertainty relations. The restrictions on measurement required in quantum physics need not, and must not, be carried over into classical physics.

It is of course possible to argue, even today, about what the complementarity of quantum concepts means. One may say that the wave and particle interpretations are 'antithetical'; but, again, it is not a question of 'dialectic', that is, of a universal feature of theory construction. Rather, we have here a very special instance: the usage of the two concepts differs in classical and in quantum physics. The fact that we employ classical concepts in quantum theory is explained by the correspondence principle, and this is never made explicit—though it may be implicit—in the account given here. This is a serious lacuna, for the principle is the most important, and a very powerful, guide in theory construction.

Complementarity, however, does not bring with it, necessarily, a different kind of logic. Though attempts have been made to use a three-valued logic for treating complementary statements, it is as yet undecided whether this is an advantage. Such a logic, of course, would never apply to the theory but only to the meta-theory.

Moreover, complementarity does not lead to what the author calls 'the principle of subjectivity'. This view, which is not very clear since entangled in obsolete philosophy, was once fashionable; but it is no longer accepted by most physicists. The rôle of the observer is no different in quantum physics from what it is in classical physics. Even in quantum theory human observers are not essential, but measurements are carried out by electronic devices, etc., which are read exactly as any other, macroscopic, apparatus. Neither quantum physics, nor the measurement of quantum phenomena, is subjective, nor is the logic underlying quantum theories. Quantum physics differs in its laws from classical physics, and the procedures of measurement differ as they also do in various parts of classical physics. The results obtained are, however, just as reliable as they always are anywhere in physics.

There are many more problems raised here than solved. What is important is to see that physicists can always arrive at some agreement about fundamental issues, however divergent their philosophic views may be.

E. H. Hutten

A History of the Theories of Aether and Electricity. The Modern Theories, 1900–1926, Sir Edmund Whittaker, F.R.S. (Thomas Nelson and Sons, London, Edinburgh, 1953. Pp. xii + 320. 32s. 6d.)

Whittaker's original *History*, which has been out of print for a long time, covered the development of the theory of the aether up to the beginning of this century. A new and modernised edition of this book appeared a few years ago. The present work was, according to the author's statement in the Preface, intended to continue the story for the period 1900–50 ; but the wealth of material compelled him to break off in the year 1926 when quantum mechanics was discovered, and to reserve the description of recent developments to a third volume.

This second volume is a magnificent work, excellent not only through a brilliant style and clarity of expression, but also through an incredible scholarship and erudition. The reviewer whose scientific life extends exactly through the period treated in the book and who has witnessed most of the events described had, by reading Whittaker's account, the feeling of re-living the past with all its excitements, its hopes, doubts, disappointments, and triumphs, and he expects that through this book something of the spirit of this heroic age of physics will be preserved. No ordinary textbook can do this. They aim at offering to the student the shortest and simplest way to knowledge and understanding, they omit all round-about ways and blind alleys and are in cases not only unhistorical but a distortion of history. Thus the reviewer has often been shocked by the attitude of modern students and young scholars who regard everything more than five years old as irrelevant prehistory. However, quite apart from the fact that previous mistakes are instructive, there are many incidents where ideas which appear today as obsolete become fertile through a slight new turn. Therefore I think that a book like Whittaker's *History* is a most essential contribution to our literature and should be read by every student of physics and of all sciences connected with physics, including scientific history and philosophy.

The book starts with a description of the empirical situation at the turn of the century, in a chapter rightly called ' The Age of Rutherford '. The next chapter has the title ' Relativity Theory of Poincaré and Lorentz ', and this title, or better the historical view expressed by it, is perhaps the only point where the reviewer does not share Whittaker's opinion. The question of attributing priority and connecting names to discoveries is a delicate one. Whittaker's whole book is a testimony to the fact that science is a collective activity of human society. He is extremely careful in mentioning obscure or forgotten papers which contain some essential new idea though perhaps in an imperfect form ; as an instructive example the beginning of chapter IV, Spectroscopy in the older quantum theory, may be mentioned, where the merits of Bohr's precursors, Conway, Bevan, Nicholson, Bjerrum, and others are duly appreciated. In the same way relativity appears in Whittaker's presentation not as a surprising discovery of a single mind, but a slow and painful development due to the labours of a number of men. The current idea is that these efforts culminated in Einstein's work, whose name has been attached to the notion of relativity. In opposition to this popular view Whittaker sees the crowning of the relativistic work in the discoveries of H. A. Lorentz and Henri Poincaré, while he regards Einstein's papers as only secondary contributions. In fact, there is much to be said in favour of Whittaker's judgment. From the mathematical standpoint the Lorentz transformations contain the whole of special relativity, and there seems to be no doubt that Poincaré was, perhaps a little ahead of Einstein, aware of most of the important physical consequences (thus, as Whittaker remarks on page 36, reversing the usual view to regard Poincaré as primarily a mathematician, and Lorentz as primarily a theoretical physicist). But why has Einstein made such a great impression that the others are forgotten by all but the specialists? It is because Einstein showed, in a very simple language, the conceptual absurdity of the idea of absolute simultaneity of distant events and succeeded not only to propose a reasonable definition of relative simultaneity with the help of light signals but also to derive, from this abstract construction, the Lorentz transformations and all their physical consequences. The reviewer is inclined, without disregarding the great contributions of Lorentz and Poincaré, to side with the general use in naming relativity after Einstein, if a name is desired at all. It may be added that there is of course in the book not the slightest bias or animosity against Einstein to be found, his name is quoted innumerable times in connection with other discoveries, mainly in quantum mechanics.

Chapters III and IV, dealing with the older quantum theory, are perhaps the most astonishing feats of learning, insight, and discrimination. For they deal mainly with complicated experimental facts and their preliminary explanations through logically rather unsatisfactory theories, which must be little attractive to a mathematical mind like Whittaker's. But just here his gift of selecting the essential and presenting the apparently incoherent steps as a reasonable exploration, by trial and error, of uncharted country is most admirable.

Chapter V, dealing with gravitation, on the other hand, is just in Whittaker's own line and of course perfect. It appears to me, especially in his last sections, as the most readable and elucidating short presentation of general relativity and cosmology. The next chapter returns to quantum theory and discusses all those phenomena and theories which, like de Broglie's waves, Bose's and Fermi's statistics, etc., provide the link between the older and the modern concepts of physics. Then comes a chapter on magnetism and electromagnetism in which a great many experimental and theoretical discoveries, partly in the frame of classical physics, partly beyond it (quantum effects) are discussed. The last two chapters give a detailed and lively account of the birth of quantum mechanics in both of its forms, matrix mechanics and wave mechanics.

In view of Whittaker's well-known interest in philosophy, the scarcity of philosophical remarks and the reluctance to take sides in fundamental disputes is most remarkable. One has the clear impression that at every important turn his sympathy is on the side of the progressive view, but his narrative is impartial and mentions many ideas which later proved to be in a wrong direction or seem to us today even a little cranky, provided they are ingenious and throw some light on the main road of development. This main road is not illuminated by beacons of praise and admiration ; the succession of great discoveries is marked only by clear statements of their scope and bearing. Thus Whittaker the conscientious historian of science, has the upper hand over Whittaker the metaphysician, and it is just this feature which makes the book a safe guide through the tangle of events.

This work makes us look forward keenly to the promised third volume.

MAX BORN

The Vienna Circle : The Origins of Neo-Positivism, Victor Kraft, trans. by Arthur Pap (Philosophical Library, New York, 1953. Pp. xii + 209. $3.75.)

THIS little book will prove most useful. The Introduction gives a welcome account of the Vienna Circle itself, and what became of its members after the invasion of Austria. The rest of the book sketches the development of the doctrines of the Circle. This will be avidly read by many who vainly try to find out what Logical Positivism is about. The author's presentation is always readable and untechnical and, if not very detailed, as thorough as is possible in the brief compass he permits himself.

The members of the circle were knit together by a common approach : the urge to philosophise scientifically. They diverged in many ways within this common approach. Still, they all seem to have held some form of the verifiability theory of meaning and some form of physicalism (epiphenomenalism, reductionism) and some form of solipsism. One merit of the present book is that it draws attention to the many problems discussed from this angle by the Vienna Circle, and thus counters the widespread impression that one or two problems were the sole focus of attention.

Several interesting facts about the Circle emerge. The central doctrines with which Logical Positivism began all had to be abandoned by their exponents. Further, we see a considerable difference between the continental and British positivists. This book of course deals only with the former. But it is plain that the Continentals were greatly concerned with the workings of science : their starting-point and goal were science ; whereas almost no British logical positivist would have claimed more than the barest smattering of this field. Not that this led to more of their work being fit for salvage.

It is an interesting matter to try to weigh the contribution to our thought of Logical Positivism ; for, although nothing remains of its individual doctrines, it undoubtedly had a most salutory and useful effect a quarter of a century ago. It threw out an enormous amount of bathwater. The baby went with it, and this might suggest that positivist action was hasty. But the bathwater had become so opaque that it was impossible to locate the baby. In this respect, therefore, the new doctrine did no harm in practice. On the other hand it gave a considerable fillip to deductive logic and axiomatics—a field where its excesses would have little influence—and to metascience. In the latter field the Vienna positivists preserved a greater realism than the British. Thus they were alive to the hypothetico-deductive procedure, though not to the full implications of this, whereas in this country inductive generalisation was taken without question to be the basis of scientific inference.

Another question the reader may wish to meditate upon concerns the beliefs now entertained by those who were logical positivists (assuming, what would be an exaggeration, that they have all given up all their positivistic beliefs) ; for there appears to be a positivistic outlook that positivists retain after they have relinquished their former doctrines. Probably the answer is that they replace their earlier views by finely attenuated versions that are the same dish, though not obviously so, with a new sauce.

The author gives a high proportion of space to a few selected philosophers. One is Carnap. An outline of his views, changes of views, and the reasons for these changes, will be welcomed by all those who find his many works formidable. Another is Popper. Here there is a peculiarity. An appended Note in the German edition, stating that he was not a member of the Circle, is unfortunately missing from the translation. But, even if it had been included, the author tells us in the text that Popper was one of the Circle—or as near as makes no difference—and gives more quotations from his *Logik der Forschung* (1935) than from any other writer. One might suppose that Popper was one of the chief inventors of logical positivist theories. But the quoted matter is uniformly severely critical of the central doctrines. And indeed the author says that Popper criticised the whole positivist theory of meaning. It is an unhappy idea to claim for a group one of its severest critics, who was not even a member. Was the author, who indicates that the continual retraction of positivistic views was due to Popper's criticisms, wishing to believe that these criticisms came from within the Circle itself?

Since the book, in addition to its ostensible content, has a good deal to do with Popper, it is appropriate to mention one or two misleading points.

With regard to observation-statements (called ' basic ' by Popper), which are used to test universal hypotheses, Professor Kraft writes that they are, for Popper, true by ' convention ' and non-empirical (p. 127). Surely what Popper meant was that, though *in one context* of testing a universal hypothesis they were stipulated or accepted unquestioningly, yet in a *different context* they could be questioned and tested, just because they were not protocol statements describing hard facts passively presented to the observer but represented *interpretations* (since all observation is shot through with interpretation). It would be seriously misleading to call this non-empirical.

Discussing Popper's theory of refutability of hypotheses (pp. 137-138) the author states that the negation of universal statements, i.e. existential statements, are verifiable. This contention takes the theory of refutability out of its context. Firstly the establishment of ' All crows are black ' for Popper depends not on verification that an observed crow is black but on failure to find a crow that is non-black on searching among the type of crow that might be expected to be non-black. This procedure cannot be described simply as verification. Secondly if we consider ' There are crows that are non-black ' on its own and claim that this is verifiable, the answer may be made that such a statement, while it plays a rôle in testing, does not occur in science as a hypothesis to be established or refuted. It might be thought that science could use ' There are germs that are invisible without a microscope ' ; but what science uses is a different type of statement, such as, ' If certain objects, which can be seen with a microscope in some specimens of blood, are injected, they will later be found in higher concentration and the patient will have more definite symptoms '—which is a *universal* statement and refutable.

One or two points of historical accuracy may be touched on. Popper is generally regarded as having initiated the attack on the verifiability theory of meaning. Professor Kraft, however, writes in such a way as to suggest—if one fails to glance at the dates of the relevant writings—that Popper was anticipated by several well-known Vienna positivists. This impression is increased by his omitting to mention Popper's Note in *Erkenntnis* (1933, 3, 426f.) and Carnap's earlier report on Popper's work in the same volume (pp. 223-224). This report, which acknowledges Popper's criticisms in detail, is vital for the history of the Circle. Again, in dwelling largely on Carnap and Popper, the author gives little hint of the profound influence of Tarski on the development of the Circle, and especially on Carnap, not only on his *Logical Syntax of Language* but on all his later work as well.

In relation to Professor Kraft's volume as a whole these defects are minor. It is a book that many people, whether philosophers of science or not, have long been wanting.

J. O. WISDOM

The Unconscious Origin of Berkeley's Philosophy, John Oulton Wisdom. (The Hogarth Press and the Institute of Psycho-Analysis, London, 1953. Pp. xii + 244. 25s.)

THIS must be the most original book about Berkeley which has appeared for a long time, and, although Dr Wisdom is concerned primarily with the psycho-analytic origin of the philosophies of immaterialism and tar-water, there is much in this book to interest the philosopher of science. It is now coming to be generally recognised that Berkeley is not only an important figure in the history of philosophy but that he also made far-reaching contributions to the philosophy of science and of mathematics. Both directly and indirectly Dr Wisdom's analysis has considerable relevance to these aspects of Berkeley's work as well.

For example, let us take Berkeley's attitude towards mathematics and mathematicians. This was not merely the critical attitude of a stubborn empiricist. Indeed, as Dr Wisdom emphasises, Berkeley did not regard his philosophy as a form of empiricism. He had a peculiarly ambivalent attitude towards mathematicians: he was fascinated by and at the same time detested them. ('All the aggressiveness in his nature', remarks Dr Wisdom, 'seemed to be concentrated against mathematicians.') This complex attitude in a man whose character and personality have been highly esteemed is certainly puzzling. Unfortunately, Wisdom clouds the issue a little by his own somewhat ambiguous assessment of Berkeley's mathematical competence. Thus on page 87 we are told that Berkeley's mathematical abilities were curiously limited, whereas on page 101 we read that as a mathematician 'he was extraordinarily gifted' and on page 157 that 'he had an excellent grasp on the most advanced mathematics of his day'. The truth probably lies somewhere between these two extremes. I believe that Berkeley was a competent student of mathematical reasoning but had no real 'feel' for the subject. Nevertheless, being gifted with the power to think clearly and the courage not to bow to the authority of any man, even if he be Newton, he succeeded in spotting major flaws in the calculus of fluxions in much the same way as the late H. W. B. Joseph is supposed to have discovered a minor mistake in the first chapter of Hardy's *Pure Mathematics.*

Instead of concentrating on the consequences of Berkeley's critical attitude to mathematics, abstract general ideas, etc., Dr Wisdom breaks new ground by looking for *unconscious causes.* To what extent he is successful must be a matter of opinion, since Berkeley himself is no longer with us and we have only his writings to go on. Moreover, if Berkeley was right in any of his contentions are we to say that that was his good luck, the silver lining, as it were, of the cloud which oppressed his unconscious mind? Dr Wisdom argues that the driving force of Berkeley's thought was an unconscious fear of bodily poison. In particular, Berkeley's attack on mathematicians was the product of his envy of their 'freedom to handle dangerous ideas and poisonous things'. This is an interesting diagnosis; and yet it is not interesting in isolation, because if Berkeley had been merely a crank no one would now bother about him or his works. Berkeley was an acute thinker, and the abiding value of his writings is totally independent of their unconscious origin.

Nevertheless, we are deeply indepted to Wisdom for his ingenious attempt to explain why Berkeley chose to direct his great mental abilities to those particular problems which did in fact engage his attention. His analysis of Berkeley must be one of the most thorough-going to which any great philosopher has yet been submitted. It would be of the greatest interest if Wisdom would undertake a similar analysis of Wittgenstein. That might be even more rewarding.

There is much more in the present book than I have so far indicated. It is divided into three parts: (1) a survey of Berkeley's philosophy; (2) an account of his life (one chapter of which appeared in this *Journal*, May 1953); and (3) the 'unconscious interpretation'. The last part includes what is perhaps the most valuable chapter in the book, on Dr Wisdom's own theory of psychosomatic order. This chapter appeared in *The British Journal of Medical Psychology* as 'A General Hypothesis of

Psychosomatic Disorder'. An account of it was given by the author in a lecture to the Philosophy of Science Group in November 1952. The core of the theory, which I understand is now being subjected to experimental test, is that a purely psychological disorder is one in which the imagination conducts basic conflicts in terms of projective images (e.g. visual), whereas a psychosomatic disorder is one in which the imagination conducts basic conflicts in terms of tactile or kinaesthetic sensations. This theory has a direct application to Berkeley since in his first major publication, *An Essay towards a New Theory of Vision* (1709), he drew a fundamental distinction between vision and touch.

G. J. Whitrow

The Philosophy of Science, An Introduction, Stephen Toulmin (Hutchinson's University Library, London, 1953. Pp. 172. 8s. 6d.)

This book is primarily intended for university students in philosophy, and a large part of it is devoted to showing up the errors in the writings of those who have not felt that lack of any experience of scientific research need prevent them from laying down rules of procedure for scientists, and interpreting their actions. It is not surprising that their works have, as the author truly remarks, a curious air of unreality about them.

Dr Toulmin discusses the place of mathematics and models in physics, and emphasises the difference between physics and natural history. He makes a much-needed distinction between different kinds of laws and principles, and between laws and generalisations, and uses his analogy between theories and maps to good effect in showing how conclusions can be obtained from theories in a manner quite different from what logicians call 'deductive inference'.

According to the book jacket, the author does not set out so much 'to propound solutions of various problems as to pave the way for solutions by providing indispensable materials for them'. This inevitably makes the book somewhat unsatisfactory; it is only the Bertrand Russells whose 'thinking aloud' is sufficiently stimulating to sustain interest although no conclusion may be reached; and Dr Toulmin does not, unfortunately, share Russell's clarity of exposition. The book-jacket commences with the assertion that it is salutary to be reminded that science is only organised common sense. This is surely one of the most misleading clichés ever invented. Aristotle and Francis Bacon could hardly be said to be deficient in common sense, yet when they organised it into scientific methods, the methods they produced differed considerably, and neither were what we call scientific method today.

A scientist reading this book is left with a feeling of uneasiness: the author's general position seems to be sound but every now and again there are disturbing statements. For example (p. 40) ' Light, as we ordinarily understand the word, is not something which can be spoken of as travelling ': (good : but then comes) ' so too, heat is no more a form of motion than dampness is a form of departure'. In so far as this statement is not obscure, it is incorrect, and all the more curious since, later on, the author instances Brownian motion as ' a demonstration that atoms and molecules really existed ' (p. 138). If the liquid is heated, the Brownian motion increases : if it is cooled, the motion decreases. Does this not support the hypothesis of a connection between ' heat ' and motion at least as cogently as it supports the atomic theory ?

Again, we have on page 54 : ' In physics, it is no use even beginning to look at things until you know exactly what you are looking for : observation has to be strictly controlled by reference to some particular theoretical problem'. This dictum gives a dangerously false impression of the procedure of physicists in so far as it undermines the primacy of experiment and observation. The present reviewer made hundreds of observations on flames sensitive to sound, on people and machines that detect underground water, and on firewalking without having any theory to guide him. The theories ultimately produced were the *result* of the observations.

In a chapter on Uniformity and Determinism, a somewhat half-hearted suggestion is put forward that the principle of the uniformity of Nature might be replaced ' entirely by the uniformity of scientific procedures '. This is not convincing, and the author himself confesses : ' it is, after all, as a result of *experience* that we find out what are the rational ways of studying the world and its contents'. Is this not what Mr Punch calls a glimpse of the obvious ?

Dr Toulmin has set himself an important task, and it is disappointing not to be able to greet the result of his labours with unqualified approval.

And one last ' cry in the wilderness '—how long will authors be allowed to use the key words *fact*, *real*, *true*, and *exist*, without telling their readers what they mean by them ?

G. Burniston Brown

Introduction to Symbolic Logic, A. H. Basson and D. J. O'Connor (University Tutorial Press, London, 1953. Pp. viii + 169. 7s. 6d.)

This must be for its size the best introduction to logic yet written. It gives a very good idea of the aims and methods of the subject. It is notable for its treatment of truth-tables, the notion of an axiom-system, and a Boolean proof of syllogistic moods. Those to whom modern logic has been a closed book but who wish to have some knowledge of the subject will welcome it. Students are certain to use it extensively.

A few criticisms may be made for the benefit of intending readers and also in case they should be useful for a second edition. (i) It would have been an advantage to have discussed validity more fully and to have included the method of counter-example, which is fundamental, instructive, and simple. (ii) Though the explanation of the use of truth-tables is excellent, the exclusive use of this method places the whole emphasis on the conception of logic as a set of tautologies ; but the conception of logic as rules of inference is slightly better and is more satisfactory intuitively. It puts the emphasis on proof, while the method of truth-tables puts it on checking. (iii) Moreover there is an advantage in presenting both methods : one is forced to explain the relation between tautologies and rules of inference, which is fundamental, interesting, and historically illuminating. The authors do not discuss this ; on the contrary (though they could not in fact be guilty of the mistake) they give the impression of confusing conditional statements and inferences (e.g. on p. 58 the ' then ' of ' if . . . then . . . ' is equated with ' therefore '). (iv) A small point. It seems a pity to perpetuate the tendency to speak of ' sentences ' as being true (or false), which is not only a barbarism but logically misleading. The natural word is ' statement '. ' Sentence ' appears to have come in partly because our continental refugees mistranslated the German and partly because our natives, frightened of ' proposition ', could think of an alternative only at the opposite extreme, unless of course the real reason is theological and traditional—a wish to preserve a link with the medievals who called their assertions ' sentences '. (v) A plea might be made for a fuller treatment of the syllogism, for the classical reduction of moods for instance, which it is not fashionable to teach, illustrates very clearly how one rule of inference may be derived from another.

With these omissions taken account of, a very good book would have been really excellent. It would be a good thing if the authors would go on to write a more advanced work, beginning where they have now left off.

J. O. WISDOM

Aesthetics and the Gestalt, Ian Rawlins (Thomas Nelson and Sons, Edinburgh, 1953. Pp. xi + 227. 18s.)

THIS book is, unfortunately, not a new work by Mr Rawlins, Scientific Adviser to the Trustees and a Deputy Keeper of the National Gallery, but a gathering of what he modestly describes in his preface as ' bits and bobs '.

Of the thirty-nine essays and reviews here republished the majority originally appeared in *Nature* and cover a span of some sixteen years, and it is useful to have collected into one volume occasional writings which have, as their author says, a common goal.

Many of these articles deal with that delicate and fascinating subject, the scientific examination of paintings, illuminated alike by Mr Rawlins' reflections and ten very interesting plates, and through all runs the common theme that a work of art is more than the sum of its parts. It is a pity that such ugly loan words as ' gestalt ' and ' prägnanz ' have to be used in describing what is now so obvious and what must, surely, have been hardly less so in the days before the gestalt psychologists came on the scene, though this is not to say that they did not perform a useful, if not a necessary, office at the time. Mr Rawlins is, however, sympathetic to neo-scholasticism, and he would probably agree that in aesthetics, about which it is difficult to say anything new that is not personal and subjective, St Thomas, while he did not say the first or the last thing, has never had his definition of beauty (*id quod visum placet*) bettered.

E. Rowan Davies

Charles Darwin's Autobiography, edited by Sir Francis Darwin (Henry Schuman, New York, 1950. Pp. 258. $3.50.)

Owing to the enormous popularity of Darwin at the time of the publication of *Life and Letters* and *More Letters* the five volumes of these works may now be purchased in England for a negligible sum. In the United States, on the other hand, no such supply exists. Hence there is a demand for a republication of the autobiography together with an extract from the letters. This little volume is the result. Who compiled it, is not stated. On what principles it has been compiled, except that the selected letters end in 1859, is also not clear. In general, the student of Darwin will probably prefer to study the originals rather than this anonymous abridgment.

C. D. Darlington

RECENT PUBLICATIONS ON THE PHILOSOPHY OF SCIENCE

(*a*) BOOKS RECEIVED FOR REVIEW

Inclusion of books in this list does not preclude their being reviewed in later issues

Harold A. Abramson, *Problems of Consciousness*, Transactions of the First Conference, The Josiah Macy, Jr. Foundation, New York, 1951, pp. 200, $3.00.

Harold A. Abramson, *Problems of Consciousness*, Transactions of the Second Conference, The Josiah Macy, Jr. Foundation, New York, 1951, pp. 178, $3.25.

Harold A. Abramson, *Problems of Consciousness*, Transactions of the Third Conference, The Josiah Macy, Jr. Foundation, New York, 1952, pp. 156, $3.25.

Harold A. Abramson, *Problems of Consciousness*, Transactions of the Fourth Conference, The Josiah Macy, Jr. Foundation, New York, 1954, pp. 177, $3.25.

Joseph Barrell, *A Philosophical Study of the Human Mind*, Philosophical Library, New York, 1954, pp. xii + 575, $6.00.

Rudolf Carnap, *Symbolische Logik*, Wien Springer-Verlag, 1954, pp. x + 209, £2/6/-.

Pierre Duhem, *The Aim and Structure of Physical Theory*, Princeton University Press (London : Geoffrey Cumberlege), 1954, pp. xxii + 344, 48s.

Aesthetics and Language, Edited with an Introduction by William Elton, Basil Blackwell, Oxford, 1954, pp. vi + 186, 21s.

Heinz von Foerster, *Cybernetics : Circular Causal and Feedback Mechanisms in Biological and Social Systems*, Transactions of the Ninth Conference, The Josiah Macy, Jr. Foundation, New York, 1953, pp. xx + 184, $4.00.

J. R. Kantor, *The Logic of Modern Science*, The Principia Press, Bloomington and Evanston, 1953, pp. xvi + 359, $6.00.

Mario Lins, *A Evolucao Logico-Conceitual da Ciencia*, Jornal do Commercio—Rodrigues & Cia, Rio de Janeiro, 1954, pp. 73.

Bertrand Russell, *Human Society in Ethics and Politics*, George Allen and Unwin, 1954, pp. 239, 15s.

Gilbert Ryle, *Dilemmas*, Cambridge University Press, 1954, pp. 129, 10s.

Richard L. Schanck, *The Permanent Revolution in Science*, Philosophical Library, New York, 1954, pp. xvi + 112, $3.00.

Dirk J. Struik, *A Concise History of Mathematics*, G. Bell & Sons, London, 1954, pp. xix + 299, 14s.

Stefan Themerson, *Professor Mmaa's Lecture*, Gaberbocchus Press, London, 1954, pp. 251, 18s.

(*b*) JOURNALS

The contents of the latest issues of other journals are printed with the advertisements on the cover of this issue

Dialectica (Switzerland), Zürich, 1953, **7**, No. 4

R. Schottlaender, ' Die Spannung zwischen Metaphysik und Erfahrung '

F. Gonseth, P. Bernays, H. Jecklin, P. Nolfi, and Th. Erismann, Symposium, ' Fondements et applications du calcul des probabilités et de statistique '

RECENT PUBLICATIONS

Dialectica (Switzerland), Zürich, 1954, **8**, No. 1

J. Piaget, ' Inconditioneés transcendantaux et épistémologie génétiquc '
H.-L. Miéville, ' Réponse à quelques critiques '
F. Gonseth, L. Vietoris, and H. Richter, Symposium, ' Fondement du calcul des probabilités II '

Methodos (Italy), Milan, 1954, **6**, Nos. 21-22

Giuseppe Vaccarino, ' L'origine delle classi '
Silvio Ceccato, ' L'origine delle classi '
Nils Aall Barricelli, ' Esempi numerici di processi di evoluzione '
Béla Juhos, ' Eind-und Zweistellige Medalitäten '
M. E. Olds, ' A note on putative and conventional truth '
Bruno Thuting, ' Methodologische Untersuchungen zur Kosmologie '
Claude E. Shannon, ' Computers and Automata '
Gustav Bergmann, ' Particularity and the New Nominalism '

Philosophy of Science (U.S.A.), Baltimore, 1954, **21**, No. 1

Elizabeth Flower, ' Comments on the Ethical Theory of Edgar A. Singer '
Jack Kaminsky, ' Corrigibility and Law '
Sidney Axinn, ' Two Concepts of Optimism '
Robert Brown, ' Explanation by Laws in Social Science '
Catherine Harris, ' Sullivan's Concept of Scientific Method as Applied to Psychiatry '
Robert McNaughton, ' Axiomatic Systems, Conceptual Schemes, and the Consistency of Mathematical Theories '
L. Haworth and J. S. Minas, ' Concerning Value Science '

Philosophy of Science (U.S.A.), 1954, **21**, No. 2

Henry Margenau, ' Can Time Flow Backwards ? '
S. B. Littauer, ' Social Aspects of Scientific Method in Industrial Production '
A. P. Ushenko, ' Truth in Science and in Philosophy '
Frank E. Hartung, ' Cultural Relativity and Moral Judgments '
Zuce Kogan, ' Methods of Furthering New Ideas '
W. H. Colburn, ' Logic and Professor Ryle '
Symposium : Philosophy of the Social Sciences
May Brodbeck, ' Philosophy of the Social Sciences '
Alan Gowirth, ' Subjectivism and Objectivism in the Social Sciences '
Richard S. Rudner, ' Philosophy and Social Science '

Philosophy of Science (U.S.A.), 1954, **21**, No. 3

E. A. Singer, Jr., ' Dialectic of the Schools '
Lester S. King, ' What is Disease ? '
Wilfred Sellars, ' Some Reflections on Language Games '
Alan Gowirth, ' Can Men Change Laws of Social Science ? '
Patrick Suppes, ' Some Remarks on Problems and Methods in the Philosophy of Science '
Adolf Grünbaum, ' The Clock Paradox in the Special Theory of Relativity '
S. Pakswer, ' Information, Entropy and Inductive Logic '
T. Foster Lindley, ' The Control in Social Experimentation '

(*c*) Articles

Ludwig von Bertalanffy, 'Philosophy of Science in Scientific Education', *The Scientific Monthly*, 1953, **77**, 233

P. Couderc, 'L'Univers est-il en expansion ?', *Scientia*, 1954, **48**, 145

J. Hirschmann, 'Instinktmechanismen im menschlichen Nahrungsverhalten', *Studium Generale*, 1954, **7**, 285

W. Mays, 'A Philosopher's Reaction to Intelligence Tests', *Philosophy*, 1954, **29**, 231

Henry Mehlberg, 'The Range and Limits of the Scientific Method', *The Journal of Philosophy*, 1954, **51**, 285

E. J. Öpik, 'The Destiny of Life', *The Irish Astronomical Journal*, 1952, **2**, 65

K. Rossmann, 'Bemerkungen zum Problem der philosophischen Interpretation in bezung auf das Verhältnis von Philosophie und Wissenschaft', *Studium Generale*, 1954, **7**, 323

The Viscount Samuel, 'Philosophy and Present-Day Physics', The Royal Institution of Great Britain, October 30, 1953, p. 203.

Abner Shimony, 'Braithwaite on Scientific Method', *The Review of Metaphysics*, 1954, **7**, 644

C. H. Waddington, 'Epigenetics and Evolution', *Evolution*, 1953, **7**, 186

C. H. Waddington, 'Genetic Assimilation of an Acquired Character', *Evolution*, 1953, **7**, 118

C. H. Waddington, 'The "Baldwin Effect", "Genetic Assimilation" and "Homeostasis"', *Evolution*, 1953, **7**, 386

C. H. Waddington, 'Evolution and Epistemology', *Nature*, 1954, **173**, 880

G. J. Whitrow, 'Reflections on Scientific Method', *The School Science Review*, 1954, **126**, 178

Richard Wollheim, 'Las "Investigaciones Filosoficas" de Ludwig Wittgenstein', *Notas Y Estudios de Filosofia*, 1954, **5**, 31